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A COMPUTER-AIDED DECISION STRUCTURING PROCESS.(U)
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June 1981

Prepared for:

OPERATIONAL DECISION AIDS PROJECT
(Codes 431, 434, 437, 455)
Office of Naval Research
Department of the Navy
Arlington, Virginia 22217

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SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
(415) 326-6200
Cable: SRI INTL MPK
TWX: 910-373-1246

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By: Miley W. Merkhofer
Ellen B. Leaf

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As a result of a multiyear research effort conducted for the Operational Decision Aids Program of the Office of Naval Research, SRI International has developed a computer-assisted, step-by-step procedure for establishing the structure of a decision problem. The structuring process consists of three phases: preliminary structuring, modeling, and expansion. Steps in the preliminary structuring phase elicit the basic factors on which the decision will be based, including decision objectives, alternatives, and critical

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uncertainties. The modeling phase organizes these factors into a formal decision model whose analysis provides insights and assistance in the identification of a tentative decision strategy. The expansion phase refines the analysis of those areas of the model to which the decision is most sensitive. Aids for implementing the process, including an interactive computer program with graphics, have been developed and subjected to preliminary testing.

CONTENTS

ILLUSTRATIONS

TABLES

1. INTRODUCTION

As part of the Operational Decision Aids (ODA) Program of the Office of Naval Research, SRI International has designed a computer-assisted, step-by-step process for structuring a decision problem into a formal decision model. To implement the process, a pilot computer aid has been developed. This report summarizes the SRI research, with an emphasis on describing the capabilities and characteristics of the pilot implementation.

Section 1 of the report provides the reader with background information, including a review of several structuring techniques that are used in the computer aid. Section 2 presents an overview of the aid and introduces the three phases of the structuring process. Section 3 describes in detail the steps in each of the structuring phases. Section 4 summarizes conclusions and suggests directions for additional research. The appendixes to the report provide additional background and technical information. Appendix A describes the use of an auxiliary manual aid for simulating military engagements and Appendix B provides technical instructions for using the computer aid as it was implemented on the ODA test-bed.

1.1 ODA Program History

The ODA Program was initiated in 1974 as an interdisciplinary effort designed to apply advances in four professional areas to the development of navy command and control systems. The four contributing areas were computer science, decision analysis, systems analysis, and organizational psychology. To focus the effort, a specific goal was defined: to develop pilot implementations of aids designed to improve decision-making at the level of the task force commander (TFC).

Several contractors, including SRI International, were selected to develop decision aids. In addition to the SRI structuring aid, other aids developed under the Program address information processing [1,2,3], man-machine communication [4,5], military outcome estimation [6,7,8], and nomography and uncertainty analysis [9]. As the aids were developed, they were installed on a computer at the Department of Decision Sciences of the Wharton School, University of Pennsylvania. The Wharton computer was used as a test-bed for experimental testing and evaluation of several of the aids [10,11].

1.2 Chronology of SRI Research Effort

This report is the fifth in a series documenting SRI's research progress toward developing a computer-aided decision structuring process. An adaptive research strategy has been applied. As a result, the current design has been strongly influenced by earlier results and conclusions.

The initial phase of the SRI research consisted of characterizing the decision environment of the TFC. Problem areas were identified in which advanced decision aids might be useful and considerations that influence the desired characteristics of potential aids were determined [12]. A key conclusion of this effort is the relative difficulty encountered by the commander in dealing with nonroutine decisions that involve uncertainty or require trade-offs of competing objectives. For many such problems, particularly those occurring during the planning phase, the need for real-time data is less than the need for a means to organize and determine the implications of readily available information. It was concluded that aids to assist the commander in structuring information would be of value, but that such aids would have to be flexible to accommodate the great variability of potential decision problems and individual methods of decision-making.

Because decision analysis techniques have proved to be highly effective in structuring corporate decisions, the second phase of the SRI research investigated whether elements of decision analysis might prove useful in typical TFC decisions. To provide a realistic decision situation for experimentation, the ONRODA Warfare Scenario [13] was used.* Experienced naval decision-makers were asked to select decision problems from the ONRODA scenario. Decision analysts then worked with the subjects to construct decision tree models of their selected problems.† The experimental structuring sessions were recorded, transcribed, and then

*The ONRODA scenario was developed by the SRI Naval Warfare Research Center for supporting development and testing of ODA Program decision aids. For a synopsis, see the footnote to page 63.
†See the next section of this chapter for a description of decision tree models.

analyzed with the objective of identifying effective structuring procedures.

The major result of this research phase was a specification of the elemental steps performed as a decision analyst structures a decision model. The research showed that the process could be represented as a sequential application of these elemental steps. When asked to comment on the process, subjects indicated that the decision tree format was valuable, citing, for example, that it countered a current tendency for plans to be optimized only with respect to most likely event outcomes. The process of constructing a decision tree not only provides a more comprehensive evaluation of each alternative, but also was found to encourage the development of new alternatives. When the decision-maker was forced to evaluate an initially preferred strategy against alternative enemy actions, he very often was able to devise modified strategies that would achieve the desired outcomes of the initial strategy with fewer significant risks.

As a final step in this phase of the research, a protocol for ordering the elemental steps of decision analysis was defined [14, p. 86] and tested to determine if it might be a helpful aid in decision structuring. The tests, conducted by members of the project team, consisted of applying the protocol to several decision problems that were concurrently being analyzed by the SRI Decision Analysis Department. The project team members then reported on what they perceived to be strengths and weaknesses of the protocol as a potential aid for military decision-making. A unanimous opinion was that the structuring protocol provided useful guidance for translating decision factors into a mathematical model, but that it failed to provide guidance for identifying the factors that should be included in the model. Two other important limitations of the traditional method of decision analysis were also apparent. Application of the traditional decision analysis procedures frequently results in the expenditure of considerable effort to model aspects of the decision problem that have little or no impact on the decision. Furthermore, the traditional method of analysis provides little indication of which alternative being analyzed is best until the final stages of the analysis. This would be a serious drawback in any environment in which the user might be forced to terminate analyses prematurely.

As a result of these conclusions, the objective of the third phase of the research was to develop techniques that would help the user identify factors likely to impact the decision and that would support a method of analysis that quickly produces a tentative solution that would be improved through additional modeling. The resulting process is called the decision tree expansion algorithm because it is based on a concept of progressively expanding a decision tree. That is, an initial decision tree model is enlarged by adding detail to those areas of the model where additional detail is most likely to indicate an improved decision [15].

Experimental applications of the decision tree expansion algorithm showed that improvements were required to make it a practical decision aid. First, a computer implementation was needed to speed and remove the burden of manually performing the computations necessary to execute the expansion algorithm. Second, procedures were needed to help the user develop the preliminary decision tree used to initiate the tree expansion algorithm. The fourth phase of the research consisted of developing a step-by-step procedure for developing an initial decision tree and implementing the basic computer code for the expansion algorithm [16]. Limited developmental testing conducted during this phase proved highly encouraging. Important characteristics of the design were identified to be:

- Flexibility--Because the computer-assisted structuring process is a general process for constructing a decision tree (one of the most flexible model formats available), it may be applied to virtually any decision situation.
- Efficiency--The aid provides tests that reduce necessary modeling effort by enabling the identification of factors that do not affect the decision before they are formally modeled.
- Realism--Restrictive assumptions, such as requiring independence of uncertainties or normal distributions for probabilities, are not required.
- Compatibility--The aid may be used with prestructured models for estimating decision outcomes (e.g., [6,7]) to produce an integrated decision aid. The integrated aid speeds decision model construction and shows how outcome calculators may be used to identify an optimal course of action.

The objective of the most recent phase of the research effort was threefold. It has been devoted to refining the structuring process, improving the design of the aid that supports the process, and completing the implementation of the aid as an interactive computer program with graphics.

1.3 A Review of Some Basic Structuring Devices

As noted in the previous section, the decision structuring process evolved from elements of decision analysis methodology found effective in experimental applications. Three fundamental elements of decision analysis play important roles in the structuring process: simulation, decision trees, and influence diagrams. To help the readers' understanding of the structuring aid, the following subsections briefly describe each of these elements.

1.3.1 Simulation

Fundamental to the decision analysis paradigm is the application of .ules of logic to estimate the consequences of alternative courses of action. The approach used is to construct a structural model, i.e., a set of mathematical relationships that represent knowledge about the behavior of the system impacted by the decision. The inputs to this model correspond to the decisions and uncertainties in the actual situation. The outputs of the model correspond to attributes of the decision outcome that are important to the decision-maker. By setting each of the model's decision variables to values that correspond to available alternatives and each of the aleatory (uncertain) variables to values that correspond to reasonable assumptions for the values of uncertainties, the model may be used to produce output values that are meant to approximate the actual outcome of the decision. Simulation is the process of estimating decision outcomes through the use of such a model.

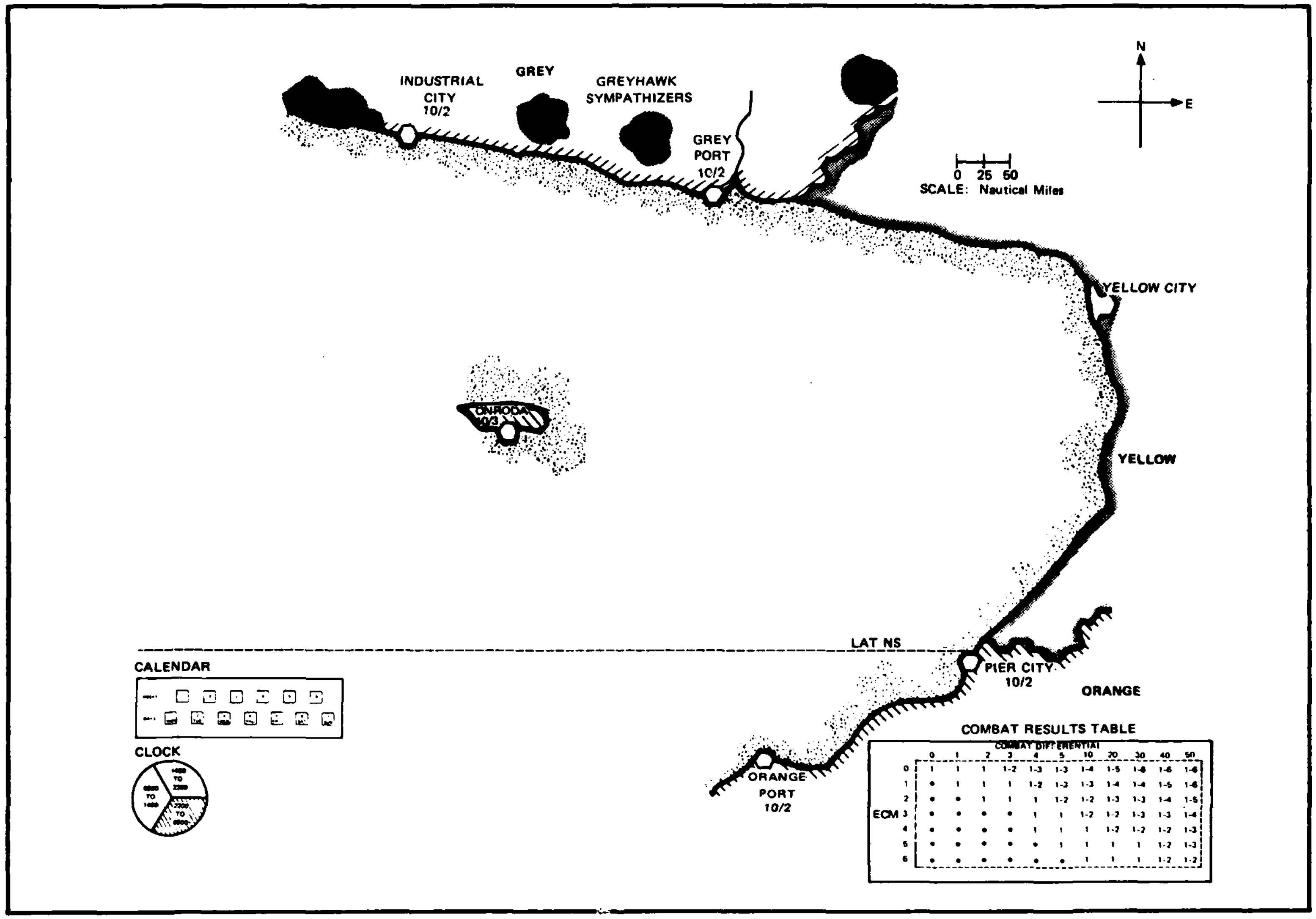
The military, especially the navy, has long recognized the value of simulation. Simulations based on manual models consisting of chart and tabletop game boards have been used by the Naval War College since the beginning of this century. More recently, computer models have played an increasing role in military simulation. The computer unquestionably offers tremendous advantages in speed and convenience over the more traditional manual techniques. Nevertheless, computer models for simulation are difficult to implement and often lack the flexibility available with manual methods. Furthermore, computer simulation generally requires large software development costs and computer hardware. As a consequence, manual methods are often the best choice for research and developmental purposes.

To support the development and testing of the computer-assisted structuring process, a manual simulation device, called a simulation board, was developed as an auxiliary aid to be used with the structuring process. This simulation board is briefly described here. A more detailed description of the rules and logic that permit the board to be used for simulation is included in Appendix A.

The simulation board is a manual war game for simulating force movements and engagement outcomes resulting from a given course of action. The game concept is similar to SEATAG [18], a simulation game developed at the Naval War College, and other commercially available war games (for example, [19]).

Figure 1 shows the playing surface for the simulation board. The surface is roughly 3 ft x 5 ft. The major feature on the board is a map of the relevant geographical region in which the task force is situated. Because experimental applications of the structuring process were conducted with decisions from the ONRODA scenario, the current configuration of the simulation board shows the hypothetical ONRODA Island and surrounding area, as specified in the scenario. The board also includes various devices and tables that are used to keep track of simulation time and to assist in the estimation of losses resulting from combat of opposing military units. A grid covers the geographic region. Playing pieces are provided to represent each force unit that may potentially become involved in combat. The game rules (Appendix A) specify constraints on the movement of the game pieces and provide logic for determining likely positions of force units and losses resulting from a given own course of action and assumed enemy response.

Figure 2 shows several of the playing pieces used with the board. Each playing piece is a small cardboard square coded to represent the movement capabilities and offensive and defensive strengths of a particular force unit appearing in the ONRODA scenario. The various force strength numbers on the left-hand side of each playing piece are selected to reflect appropriate exchange ratios. (Matching the offensive and defensive strengths of opposing units produces loss outcomes that are consistent with published exchange ratios.) The numbers on the right-hand side reflect the unit's speed and range capabilities, defensive strength, and ability to avoid detection through the use of electronic



ECM	0	1	2	3	4	5	10	20	30	40	50
0	1	1	1	1-2	1-3	1-3	1-4	1-5	1-6	1-6	1-6
1	•	1	1	1	1-2	1-3	1-3	1-4	1-4	1-5	1-6
2	•	•	1	1	1	1-2	1-2	1-3	1-3	1-4	1-5
3	•	•	•	•	1	1	1-2	1-2	1-3	1-3	1-4
4	•	•	•	•	1	1	1	1-2	1-2	1-2	1-3
5	•	•	•	•	•	1	1	1	1	1-2	1-3
6	•	•	•	•	•	•	1	1	1	1-2	1-2

FIGURE 1 THE SIMULATION BOARD

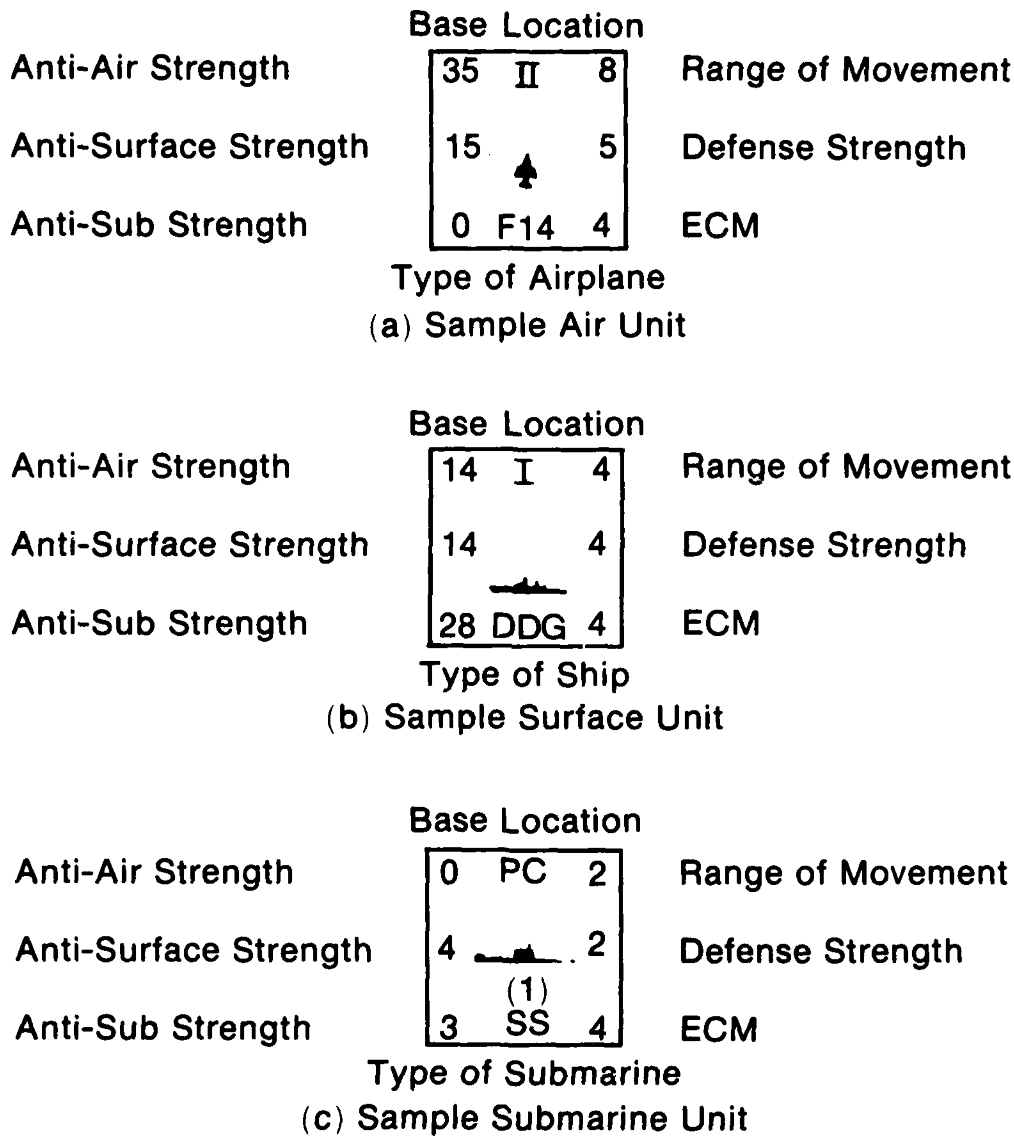


FIGURE 2 TYPICAL SIMULATION PLAYING PIECES

countermeasures. A method of table-look-up is used to obtain probabilities for possible outcomes to each combat engagement.

As described in Sections 2 and 3, the simulation board is used as an auxiliary aid for evaluating alternatives. The user moves the game pieces corresponding to his forces to reflect a given course of action. He then moves enemy pieces according to potential enemy responses. Applying the rules for simulating combat and using the combat results table, the user may estimate engagement outcomes. In practice, the user will make small adjustments to each proposed strategy so that, when he plays it out on the simulation board, he minimizes his likely losses for a given level of effectiveness.

The manual implementation of the simulation board provides sufficient detail to model the complex interactions of an engagement between opposing naval forces and yet is flexible enough to accommodate several different scenarios without extensive redesign. Although the board is currently implemented as a manual system, it could be fully automated.

1.3.2 Decision Trees

As noted previously, the form of the decision model produced by the structuring process is a decision tree. The decision tree format was selected because it is a general model form that has been successfully applied to a wide variety of decision problems. Decision trees are particularly well suited to representing dynamic decisions involving uncertainty, a characteristic typical of decisions facing the TFC.

Figure 3 illustrates a decision tree model for a TFC planning decision taken from the ONRODA scenario. According to the scenario, the TFC of Blue forces has been assigned the mission of neutralizing an enemy attack anticipated to be launched from ONRODA airfield against a Blue ally.* The decision is whether the Blue TFC should plan to neutralize the ONRODA airfield with an air strike or with a blockade. Important considerations for this decision, represented in the tree, include whether Red, which is allied with the enemy, has civilian aircraft (such as hospital planes) on the airfield when the commander launches the air strike and whether Red will attack the task force in retaliation for the Blue TFC's actions.

In the decision tree format, decisions are represented by small squares, called decision nodes, with the various alternatives shown as lines emanating from each square. Uncertainties, such as enemy actions, are represented in the diagram by small circles, called chance nodes. The branches emanating from chance nodes represent the possible outcomes to each uncertain event.

The decision and chance nodes in a decision tree are arranged according to the sequence in which decisions must be made and in which outcomes of uncertain events will be revealed to the decision-maker. Thus, each path leading from left to right through the tree represents a different possible sequence of decisions and events. As an example, suppose the commander chooses to plan an air strike. The decision tree shows

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*For a synopsis of the ONRODA scenario, see the footnote to page 63.

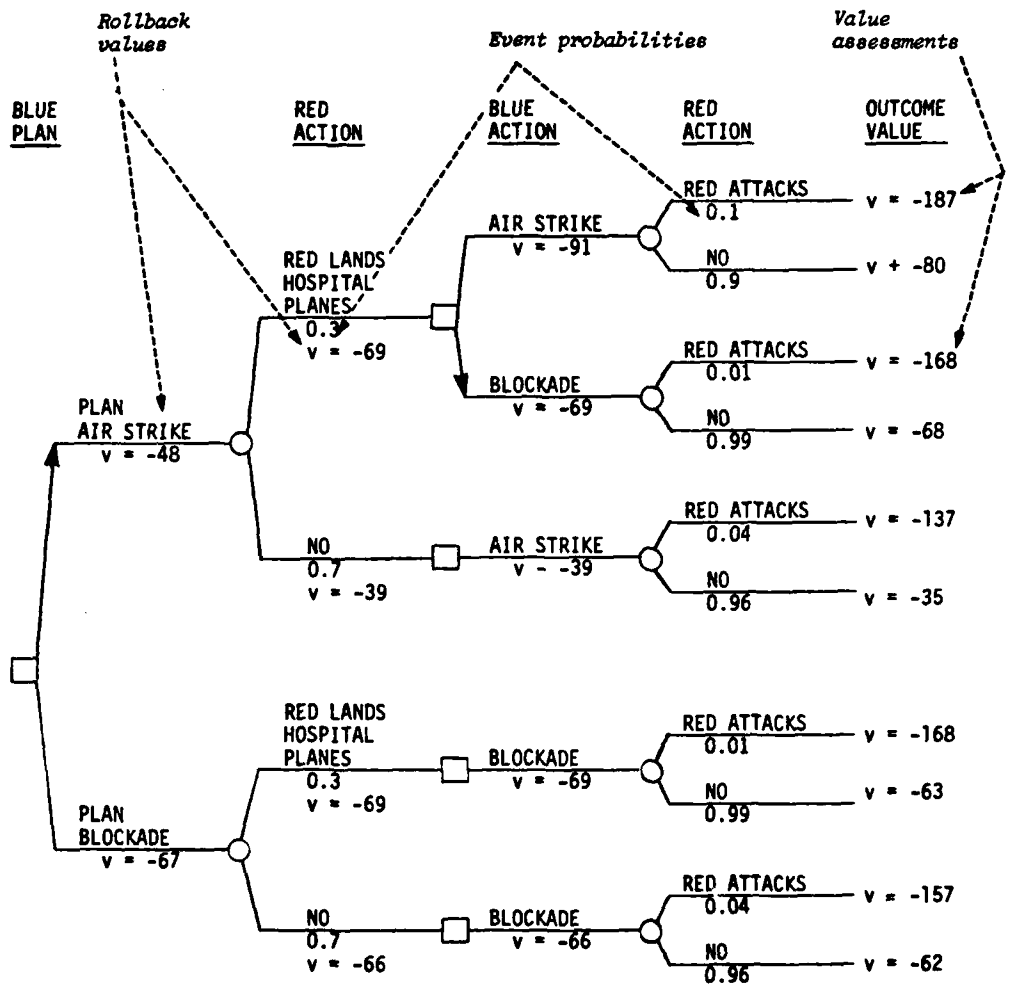


FIGURE 3 DECISION TREE REPRESENTING PLANNING DECISION TAKEN FROM THE ONRODA SCENARIO

that reconnaissance will indicate whether Red has hospital planes on the airfield before the attack. If hospital planes are sighted, the commander can either launch his air strike or revert to a blockade. Following whatever action is chosen, Red may or may not attack the task force.

The principal value of a decision tree is that it can be solved to obtain an optimal decision strategy. The strategy is optimal in the sense that it maximizes expected value (or minimizes expected loss). The first step in solving the decision tree is to provide the necessary numerical inputs--probability assessments for the likelihood of the various outcomes to uncertain events and value assessments representing the relative desirability of each path through the tree. Figure 3 shows example probabilities under the branches from chance nodes and sample values at the terminal points of the paths through the tree.

The next step is to compute expected values for each node in the tree. Expected values can be obtained using a rollback procedure. The expected value at a chance node may be obtained by multiplying each terminal value by the probability along the branch leading to that value and adding. Similarly, if the rule is used that the decision-maker will prefer the decision alternative with the highest expected value, the expected values for decision nodes can be determined.

Rolling expected values back through the decision tree in this manner enables the decision strategy that maximizes expected value (or minimizes expected loss) to be determined. For the example, computed expected values indicate that the optimal initial decision is to plan an air strike. The optimal decision strategy is to execute the air strike if no Red hospital planes are sighted and to revert to a blockade if Red hospital planes are sighted.

Selecting decision trees as the model for decision structuring has a number of advantages. Most importantly, as mentioned earlier, the decision tree is a general model form that can be used to represent a wide variety of decision situations. Another advantage is that a decision structuring process based on decision trees is compatible with the use of prestructured models. In a prestructured model, the relevant factors and relationships for a specific class of situations that may be encountered are identified and modeled in advance. These models are then programmed on a computer and used for simulation. Within the structuring process, prestructured models can be used for simplifying the generation of numerical inputs. Specifically, models can be developed to help estimate the probabilities associated with chance nodes, the outcomes associated with each path through a decision tree, and the values to be assigned to the terminal points of each path through a tree. For example, if an air strike outcome calculator were available for estimating the military outcomes under various strike patterns, it could be used in conjunction with the decision tree in Figure 3 to produce an integrated decision model.

Another major advantage to structuring a decision as a decision tree is that the methods for analyzing and solving decision trees are easily programmed. Thus, the same computer aid that helps construct the decision tree can be used to solve it. More importantly for a decision structuring process, a computer can be used to analyze a decision tree structure to identify how that structure should be expanded so as to improve its reliability. This idea, which lies at the heart of the computer-assisted structuring process, is described in Sections 2 and 3.

1.3.3 Influence Diagrams

Although decision trees are a convenient model form for analysis, they are not effective for graphically portraying probabilistic dependencies in the decision problem. Influence diagrams are graphical devices specifically designed to summarize the dependencies that exist among the variables in a decision [20]. A close relationship between influence diagrams and decision trees makes it possible in many cases to develop a decision model in the form of an influence diagram and then to convert the diagram to a decision tree for analysis. The advantage of beginning with an influence diagram is that these diagrams have considerable intuitive appeal apparently because their graphical representations correspond closely to the way many decision-makers conceptualize their problems.

Figure 4 shows how influence diagrams represent the dependencies among variables. As with the decision tree, aleatory variables (representing uncertainties) are denoted by circles and decision variables are denoted by squares. An arrow pointing from an aleatory variable A to an aleatory variable B means that the outcome of A can influence the likelihood of the various outcomes associated with B. Stated more precisely, it means that the probability distribution assigned to B may be conditioned on the outcome of A. An arrow pointing to a decision variable from either another decision or aleatory variable means that the decision is made with knowledge of the outcome of the decision or aleatory

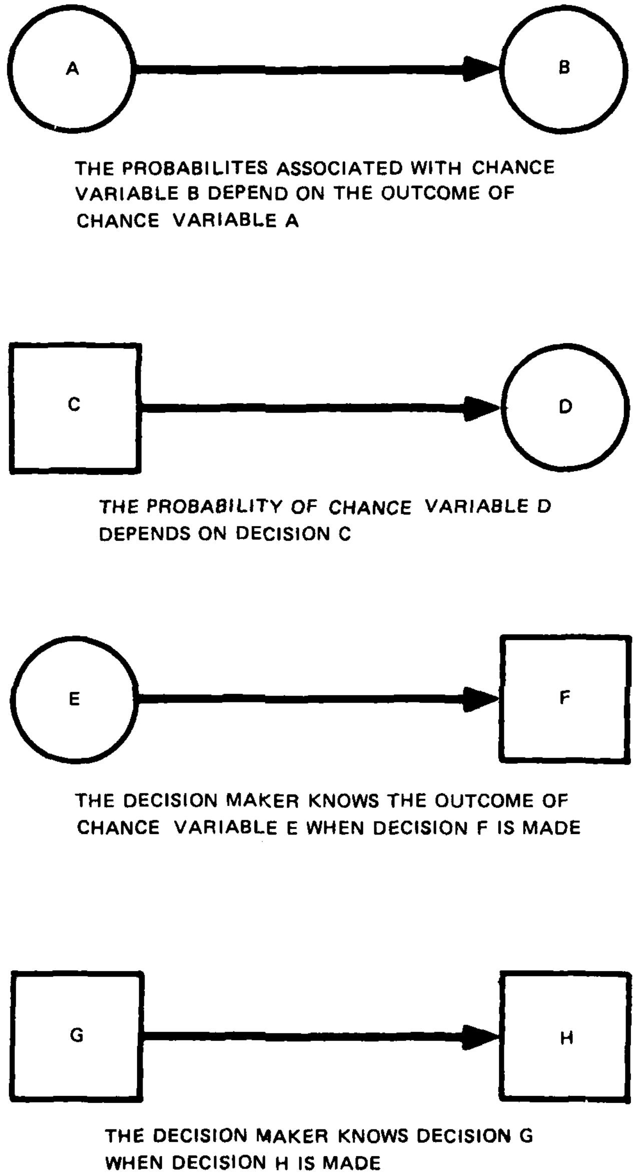


FIGURE 4 DEFINITIONS USED IN INFLUENCE DIAGRAMS

variable. A connected set of squares and circles is called an influence diagram because it shows how aleatory variables and decisions influence each other.

Figure 5 shows an example of an influence diagram. The circles a, b, c, e, g, h, i, j, k, l, m, and o all indicate aleatory variables whose probabilities must be assigned given their respective conditioning influences. For example, the probability assignment for variable i must be conditioned upon variables f, g, and l and only on these variables. The squares d and n represent decision variables that must be set as a function of their respective informational influences. As an example, the decision variable d is set with knowledge of variables a and c and only with these variables. Thus, the decision d will typically be a function of the values of a and c.

A process for constructing influence diagrams is described in decision analysis literature [21]. Typically, an analyst constructs an influence diagram in an interactive interview with the decision-maker (or technical expert designated by the decision-maker) as the subject. Once the subject is satisfied that the influence diagram accurately represents the influences among the variables in his problem, the decision analyst will attempt to translate the influence diagram to a decision tree for processing.

To describe the conditions under which an influence diagram can be converted to a decision tree, it is necessary to introduce some additional terminology.

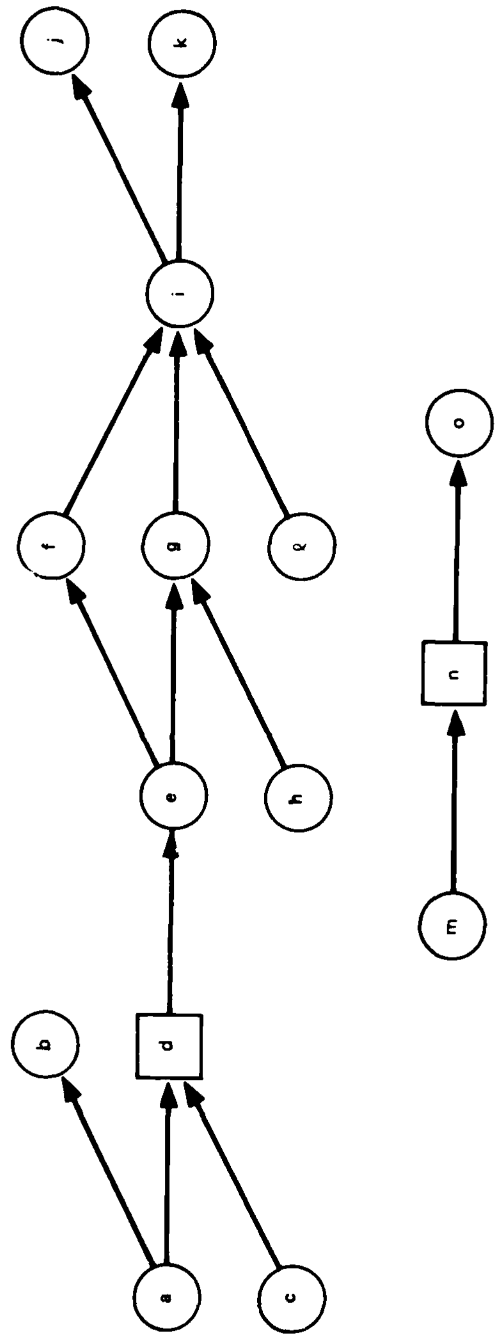


FIGURE 5 AN INFLUENCE DIAGRAM

- The <u>predecessor set</u> of a node in an influence diagram is the set of all nodes having a path (series of connecting arrows) leading <u>to</u> the given node.
- The direct predecessor set of a node is the set of nodes having an influence arrow connected directly to the given node.
- The successor set of a node is the set of all nodes having a path leading from the given node.
- The direct successor set of a node is the set of nodes having an influence arrow connected directly from the given node.

As an example, Figure 6 shows the composition of each of these sets in relation to the node g.

Two conditions are required to permit an influence diagram to be represented as a decision tree. First, the diagram must contain no loops. A loop would indicate that a variable both influences and is influenced by another variable, a condition that cannot be represented by the strict left-to-right ordering of variables in a decision tree. Second, if the diagram is meant to represent a single decision-maker who does not forget information, then the direct predecessor set of one decision must be a subset of the direct predecessor set of any subsequent decision. In the influence diagram of Figure 5, decisions d and n have mutually exclusive direct predecessor sets, (a,c) and (m). Again, because of the strict ordering of variables in a conventional decision tree, this situation cannot be represented.

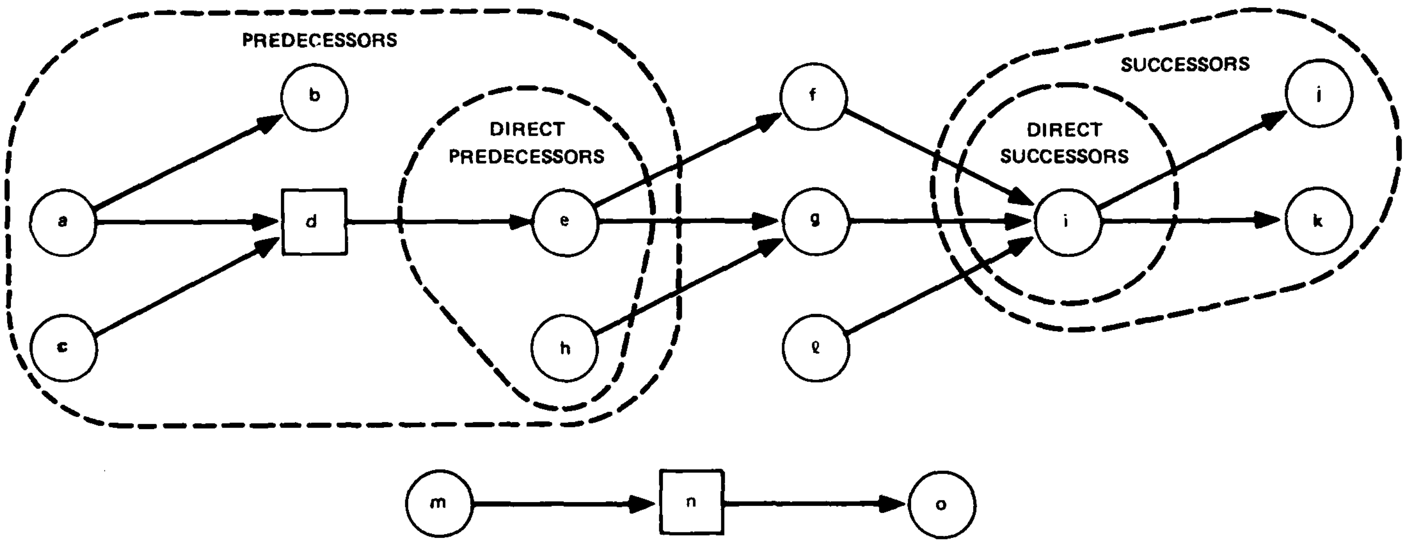


FIGURE 6 SOME SETS DEFINED BY THE NODE g

Influence diagrams that satisfy these conditions are called decision tree networks. Many different, but mathematically equivalent decision trees can be constructed from an influence diagram that is a decision tree network. The only conditions are that the decision tree must preserve the ordering represented by the arrows in the influence diagram and that the tree must not have a chance node as a predecessor of a decision node for which it is not a direct predecessor. This would imply that the decision could depend on the chance node, but according to the influence diagram, this is not the case.

A procedure for constructing a decision tree from an influence diagram begins with an identification of a node with no predecessors (a node with no arrows pointing toward it). Because the diagram is assumed to be a decision tree network, there will be no loops, and therefore at least one node will have no predecessors. If there is a choice between decision and aleatory variables, a decision variable must be selected. The selected variable is placed at the beginning (left-hand side) of the tree, and the corresponding node is removed from the influence diagram. The reduced diagram must contain at least one node that has no predecessors, and one of these is selected. Again, if there is a choice, a decision variable must be chosen. This variable is placed in the second level of the tree, and the corresponding aleatory variable is deleted from the diagram. This same procedure is repeated through all levels until all of the variables have been removed from the influence diagram.

The most significant step in the construction of a decision tree, specifying the limitations on possible conditioning, is determined by the influence diagram. To complete the tree, however, the possible outcome values for each variable must be specified and probabilities quantified. The routine process of collecting the required additional information and constructing the tree can be reduced to an algorithm. As described in Sections 2 and 3, such an algorithm has been developed and is contained within the decision structuring process.

2. OVERVIEW OF THE DECISION STRUCTURING PROCESS

This section presents an overview of the structuring process and its associated aids. A more detailed description and illustration of the process is presented in Section 3.

2.1 Three Phases of Structuring

Figure 7 illustrates the major components of the computer-aided decision structuring process. The process has three distinct phases: preliminary structuring, modeling, and expansion. The preliminary structuring phase is designed to translate the unstructured problem confronting the decision-maker into a structured problem statement expressed in outline form. The primary computer aid in this phase is called the Computer Program for Systematic Inquiry. Next, the modeling phase produces an initial simple decision tree model. The initial model includes only the most important factors identified in the preliminary structuring phase. The primary computer aid is a Program for Influence Diagram and Decision Tree Construction. Last comes the expansion phase. Because the first model is likely to overlook important factors that were not immediately apparent to the decision-maker, the expansion phase is designed to identify and bring into the initial model additional factors that may affect the decision. The primary computer aid is a Program for Decision Tree Expansion and Analysis.

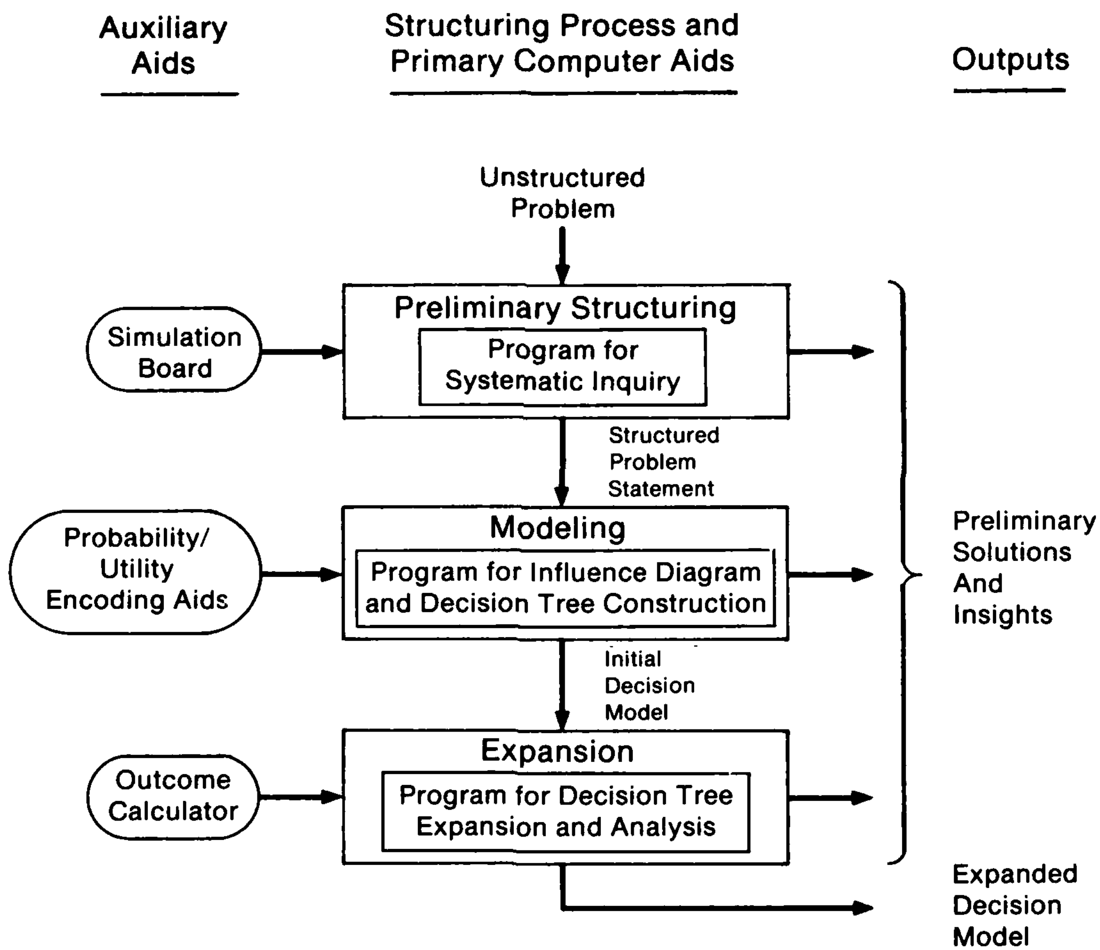


FIGURE 7 OVERVIEW OF THE COMPUTER-AIDED STRUCTURING PROCESS

In addition to the primary computer aids, the process could usefully incorporate several auxiliary aids. Auxiliary aids for outcome estimation [6], probability encoding [22], and utility assessment [23] would be especially useful. As will become clear in subsequent sections, application of the structuring process requires the user to supply quantitative estimates for the outcomes that might occur under various decision alternatives and assumptions. Naval planning officers have been trained in various rules-of-thumb for estimating military outcomes, but providing a large number of outcome estimates can become burdensome if calculated by hand. In the preliminary structuring phase, a simulation board (described in Section 1.3.1) is used as an auxiliary aid for estimating decision outcomes. For use in the modeling and expansion phases, an analogous, but computerized simulation device, called an outcome calculator, is recommended. The process may be used without auxiliary aids; however, their use is likely to improve the quality of results and significantly reduce time requirements.

The ultimate output of the structuring process is a fully structured decision tree model together with insights and solutions produced through an analysis of that model. Interim outputs include a structured problem statement and a series of preliminary models and solutions. Because the decision model is improved as it is expanded to include more and more of the relevant decision factors, the preliminary solutions are improved as the process is continued. Having a continuously available tentative solution is valuable because the structuring process may be usefully terminated at any point. The most recent model and its solution provide an approximation to the optimal decision strategy that would be produced if the structuring process were carried out to completion. In practice, the decision-maker will terminate the structuring process whenever he perceives that the improvements to be gained from further structuring and analysis do not warrant additional investment of his time.

2.2 Concept of Operation

Decision structuring is largely a creative activity. Although some technical aspects of structuring can be formalized (indeed, this has been the subject of this research), training and experience are essential for anyone who attempts to construct models that will be used to support decision-making. It may or may not someday be possible to develop highly sophisticated, interactive computer programs that for practical purposes duplicate the role of the experienced analyst. Such an aid, if it could be built, would be designed to be operated by a decision-maker who has very little training in decision analysis. Current technology, however, is a long way from this ideal.

Our computer-assisted decision structuring process is designed to be implemented as a man-machine system. Figure 8 illustrates the interactions among the various components. The computer aids are operated by an analyst with a moderate level of training in decision analysis. The analyst works with the decision-maker to structure a model that reflects the decision-maker's view of his situation. In the TFC environment, the analyst would be a member of the commander's staff, and the computer aids would be located on his flagship.

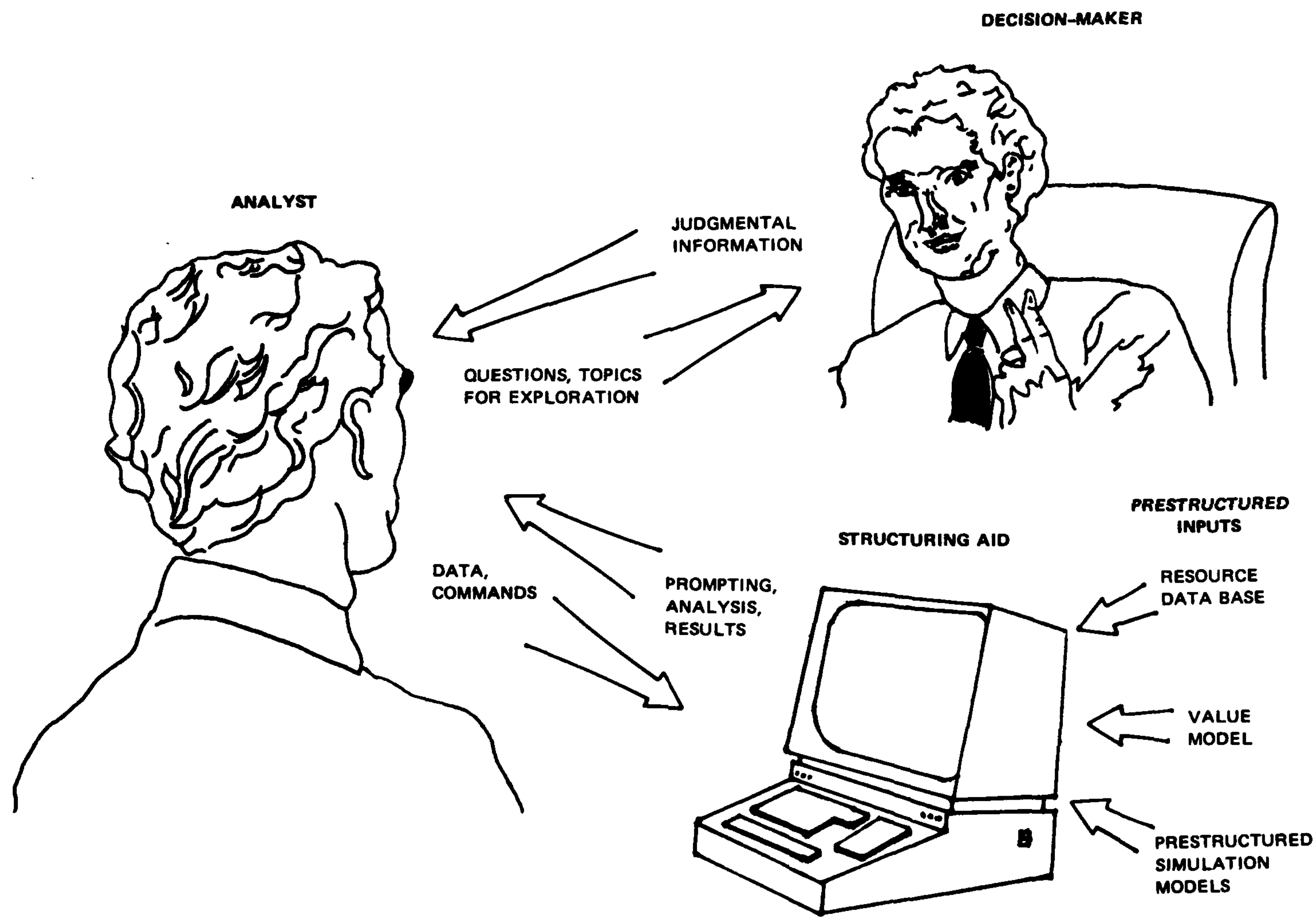


FIGURE 8 IMPLEMENTATION OF THE STRUCTURING PROCESS AS A MAN-MACHINE SYSTEM

From the decision-maker's point of view, structuring activity consists of a well-directed dialogue with the analyst. The analyst asks specific questions regarding the commander's assessment of the situation and suggests issues for detailed discussion. The decision-maker, in turn, is responsible for providing (or verifying) the judgmental inputs required for the analysis. The computer prompts the analyst with an orderly sequence of questions and data requests for building a decision model. The analyst enters the required data, translating or interpreting information provided by the decision-maker, if necessary. The decision model developed and the results of analyzing the model are displayed to the analyst, who conveys the information back to the decision-maker. Both the prompts and the decision structure produced by the computer are determined by analyses that the computer carries out on the basis of various data provided to it; namely, the interactive inputs provided by the analyst and various prestructured data bases.

Prestructured data bases contain relevant information that is not likley to change frequently. These data fall into 3 classes: information concerning the characteristics of resources available to the decision-maker, a value model expressing the decision-maker's willingness to trade off one outcome attribute for another, and prestructured models that can be used for simulation. If the decision-maker is a TFC, information concerning his resources would include the number, type, and capabilities of his various force units. The value model would describe the relative importance of the relevant attributes of the decision outcome--for example, willingness to trade off own force losses of various types for accomplishing the mission ·h·je · · Tresturc·ured models would be military outcome calcula· ·s. Existi· pres·ructu·ed decision aids, such as the Stri· · ·· Calculator · ·he Strike Timing Aid [7], and the Emissions Contro. Planning Aid . d, with only minor modifications to their codes, be used as outcome calculators. As mentioned previously, the structuring aid can be used without using outcome calculators; however, the use of outcome calculators permits the structuring process to be conducted in the most rapid and efficient manner possible.

To operate the aid, the only prestructured data that are required are a value model and the absolute minimum and maximum possible values for each outcome variable contained in the value model. Appendix B describes the manner in which these data are provided to initialize the structuring aid. Value models and their use in the structuring process are described more thoroughly in Section 3.2.

2.2.1 Hardware Configuration

The interactive computer programs for applying the decision structuring process were designed and implemented on the ODA test-bed facility at the University of Pennsylvania. Figure 9 shows the hardware configuration. As illustrated, three video screens were available for simultaneous display of outputs: a color monitor tied to a Grinnel display system for representing decision trees and influence diagrams, a CONAPL graphics terminal for alphanumeric input and output, and a Tektronix 4013 for plotting probability distributions. Available input devices consisted of a keyboard and track ball.

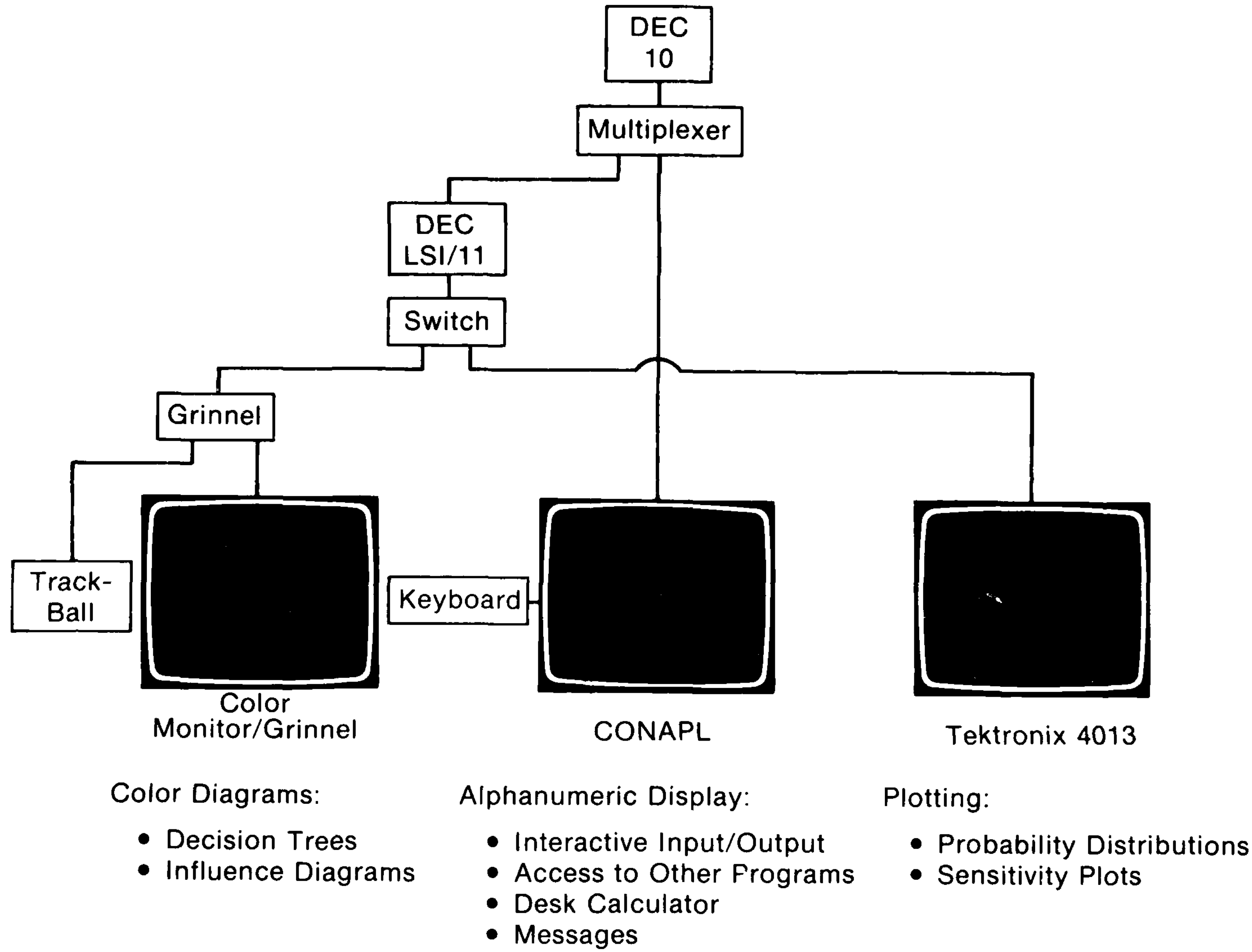


FIGURE 9 TEST-BED HARDWARE

Figure 10 shows equipment used for remote access of the test-bed from SRI Menlo Park offices. A Ramtek 6800 was used for graphic displays, and an APL terminal (Datamedia) was used for interactive input and output. Remote access was over the ARPANET.

2.2.2 Graphics Capability and Operation

Figures 11 through 18 provide examples of the output display formats produced by the computer aid at various points in the structuring process. A brief description of the operating principles of the aid are included here to help the reader understand the manner in which a user would interpret and make use of the various graphic outputs. A detailed explanation of the structuring process and its application is presented in Section 3.

In the preliminary structuring phase, the Program for Systematic Inquiry is essentially an automated questionnaire with questions and user responses displayed on the alphanumeric display terminal. The advantage of automating the questionnaire is that it allows prompting detail to be adjusted to the needs of the user. Figure 11 shows a typical display format illustrating a point in the questionnaire where the user has the option of requesting a "template" of possible responses.

As described earlier, the simulation board is an auxiliary aid used in the preliminary structuring phase to help estimate military outcomes to alternative courses of action. Figure 12 illustrates the manner in which the simulation board is used in conjunction with the Program for Systematic Inquiry. The user temporarily goes "off-line" to operate the

FIGURE 10 EQUIPMENT USED AT SRI FOR REMOTE ACCESS OF THE TEST-BED OVER ARPANET

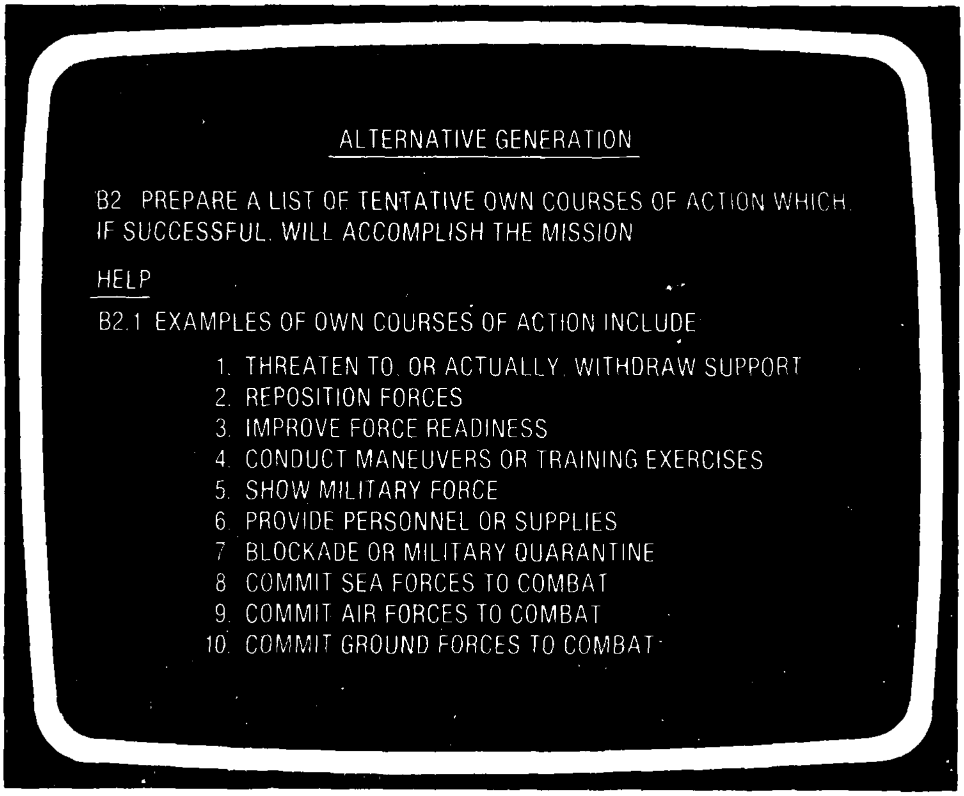


FIGURE 11 TYPICAL ALPHANUMERIC DISPLAY
DURING THE PRELIMINARY STRUCTURING PHASE

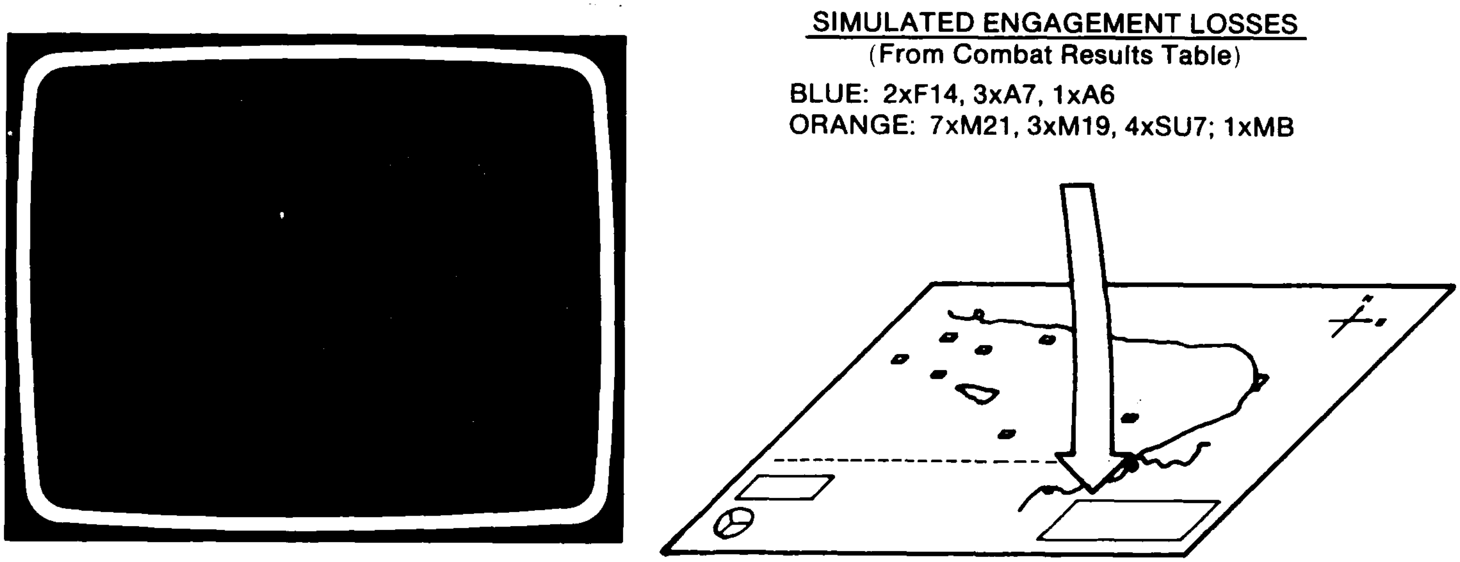


FIGURE 12 USING THE SIMULATION BOARD WITH THE COMPUTER AID TO ESTIMATE MILITARY OUTCOMES OF ALTERNATIVE COURSES OF ACTION

simulation board and then continues the program when he has completed the simulation.

In the modeling phase, the Program for Influence Diagram and Decision Tree Construction is used to translate the problem statement developed in the preliminary structuring phase into a simple decision model. Figure 13 shows the initial interaction as displayed on the alphanumeric terminal screen. The color monitor is used to display graphical representations of the models. Figure 14 shows the manner in which the two video screens are used simulataneously for constructing an influence diagram. Figure 15 illustrates the simultaneous use of the screens for converting the influence diagram to a decision tree. As part of the process of constructing the decision tree, high, best, and low estimates are required for different variables in the model. The computer converts these estimates to probability distributions that, as shown in Figure 16, may be displayed on a graphics terminal, if available, or output on a hard-copy plotter.

Although not visible in the black and white illustrations of this report, decision trees and influence diagrams are displayed using color. For example, a color reproduction of the decision tree display in Figure 15 would show the alternative with the highest expected value (or lowest expected cost) denoted with a blue arrow. The path through the tree recommended for additional structuring--the path with highest "VOM" (for Value of Modeling)--is highlighted in red. In this case, the highlighted path is AIRSTRIKE followed by NO RED AT. The concept of the VOM and the

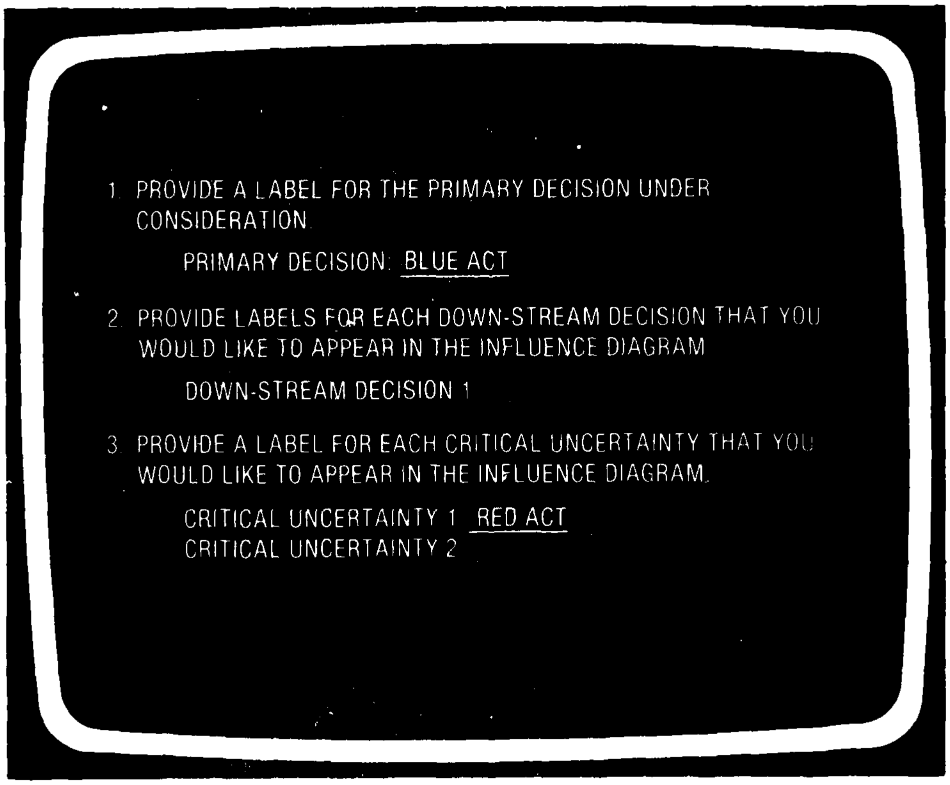
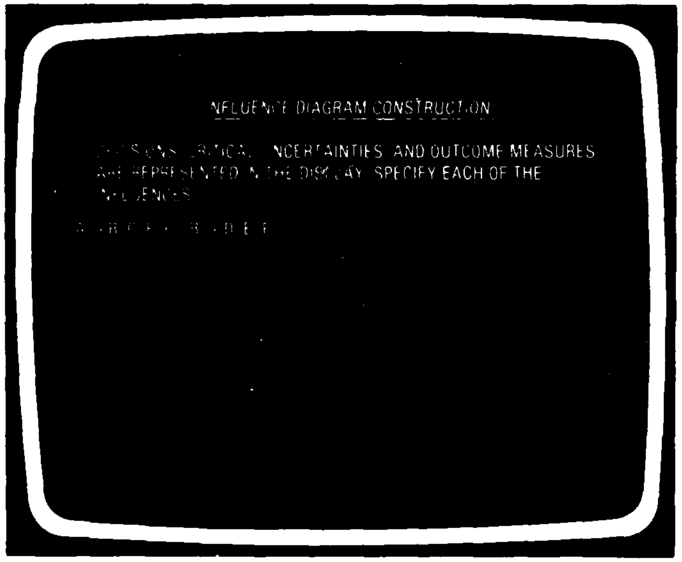
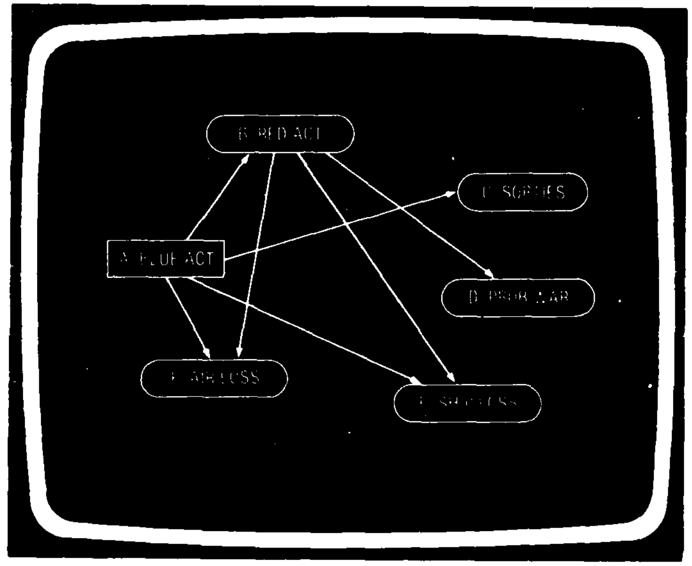


FIGURE 13 TYPICAL INITIAL DISPLAY DURING THE MODELING PHASE

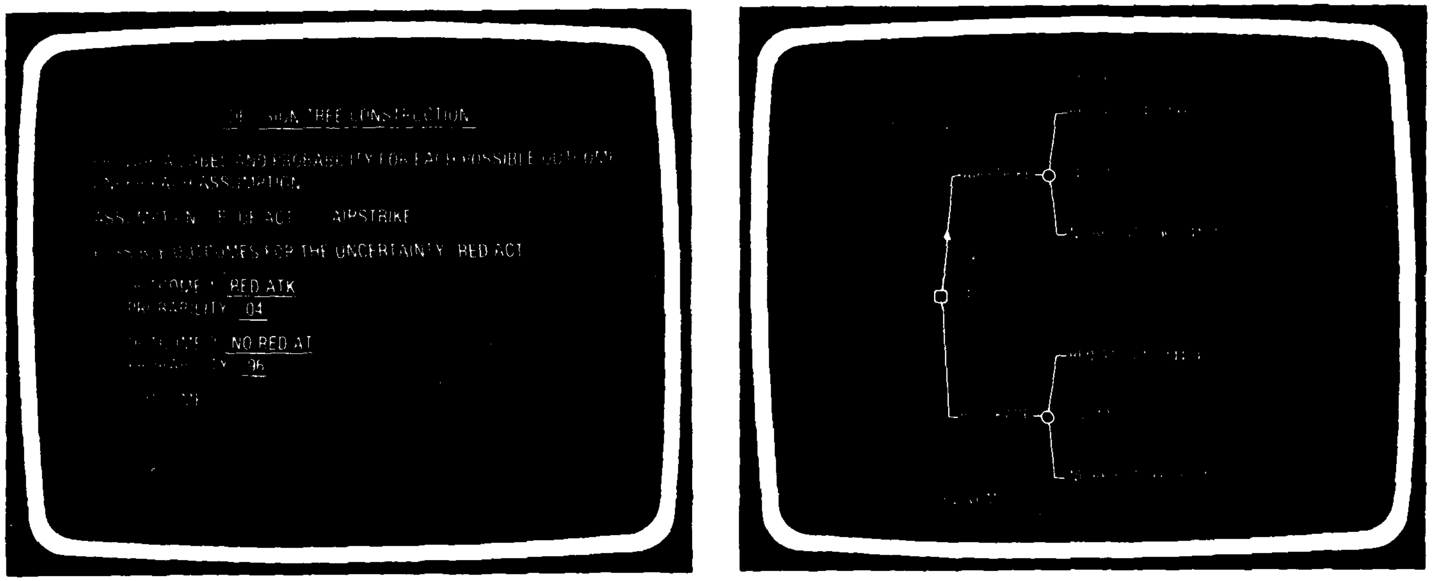


DATA MEDIA



COLOR MONITOR

FIGURE 14 SIMULTANEOUS USE OF THE ALPHANUMERIC DISPLAY AND COLOR MONITOR FOR CONSTRUCTING INFLUENCE DIAGRAMS



DATA MEDIA   COLOR MONITOR

FIGURE 15 TYPICAL DISPLAYS FOR DECISION TREE CONSTRUCTION

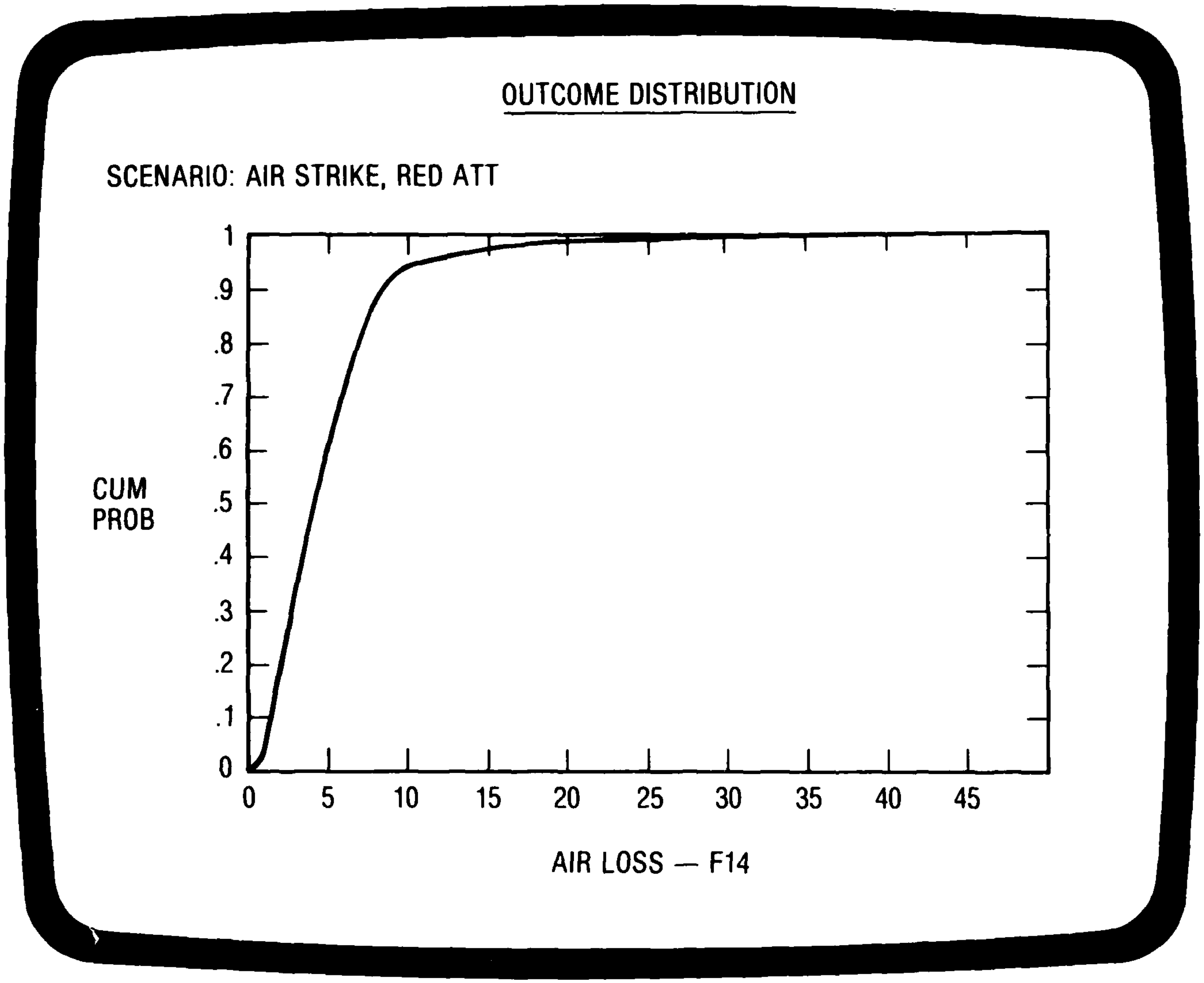


FIGURE 16 DISPLAY SHOWING PROBABILITY DISTRIBUTION PLOT

logic behind recommending a path for additional structuring is described in previous SRI reports [15, 16].

In the expansion phase, the Program for Decision Tree Expansion and Analysis assists the user in identifying and adding to the initial model other factors that may affect the decision. To accomplish this, the program formulates questions that help the user probe specific areas of the initial model, as illustrated in Figure 17. The areas probed are determined by the computer through sensitivity analysis. Factors identified are tested to determine their importance, and the most important factors are added to the influence diagram and decision tree.

Figure 18 shows the display of the expanded decision tree. Again, the results of analyzing the tree are highlighted with color--the alternative with the highest expected value (lowest expected cost) is noted with a blue arrowhead and the path through the tree recommended for additional structuring (AIRSTRIKE followed by NO SAMS followed by NO RED AT) is highlighted in red. This figure represents the principal output of the structuring process--a decision tree model of the user's decision situation and an analysis of the model including an indication of where any additional structuring effort should be directed.

2.3 Sample Application

Table 1 gives a complete sample application of the structuring process, showing input and output and graphic displays produced by the computer aid. This example does not illustrate all capabilities of the aid.

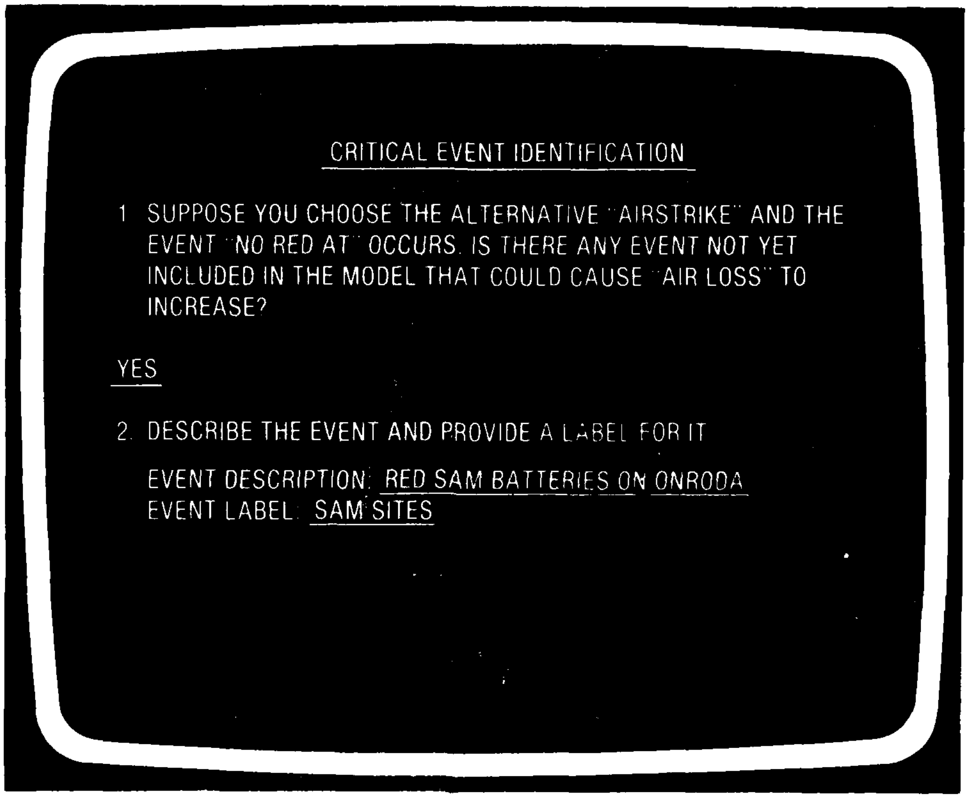


FIGURE 17 TYPICAL INITIAL DISPLAY DURING THE EXPANSION PHASE

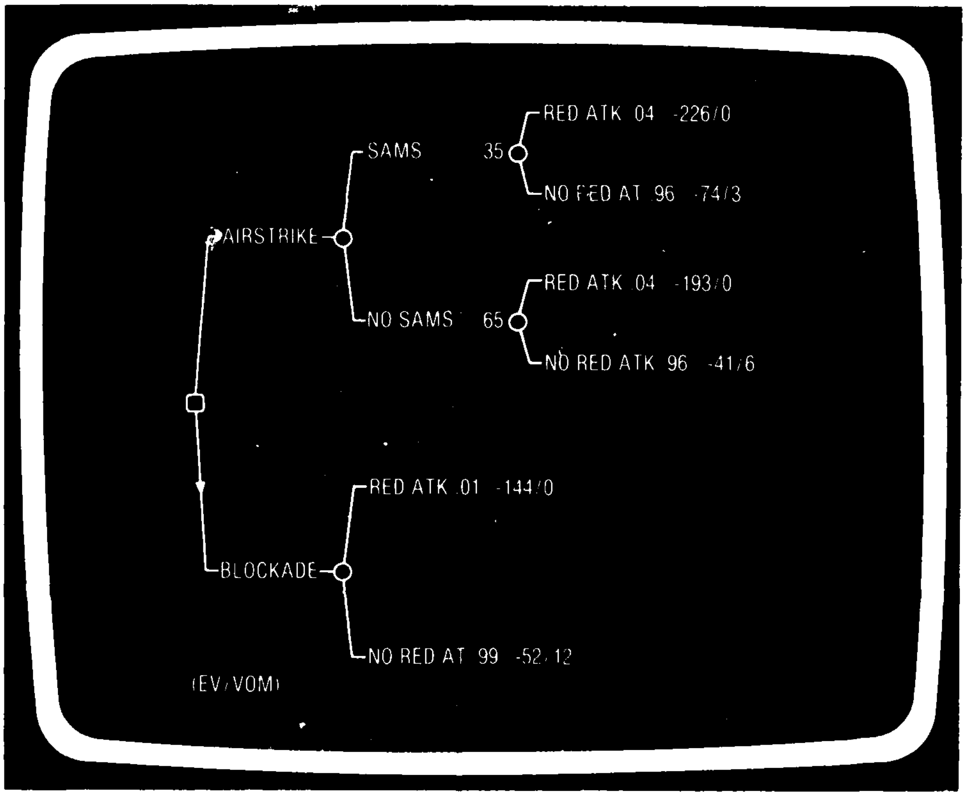


FIGURE 18 TYPICAL DISPLAY SHOWING EXPANDED [illegible] STRATEGY WITH LOWEST EXPECTED COST (EV) AND [illegible] HIGHEST VALUE OF MODEL [illegible]

Table 1

SAMPLE APPLICATION OF THE STRUCTURING AID

PRELIMINARY STRUCTURING PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
A1: WHAT IS THE INCENTIVE OR REASON FOR THE ASSIGNED TASK? *ORANGE IS PREPARING TO ATTACK GREY*	Beginning of the objective identification function.
A2: WHAT ARE YOUR SUPERIOR'S OBJECTIVES? 1. *PREVENT THE ORANGE ATTACK* 2.	
A3: WHAT IS THE OBJECTIVE OF THE MISSION? IF THE MISSION HAS MULTIPLE OBJECTIVES, LIST THEM. 1. *NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND* 2. *MINIMIZE OWN FORCE LOSSES* 3.	
A4: WHAT SPECIFIC, QUANTITATIVE MEASURES COULD BE USED TO INDICATE THE DEGREE OF MISSION SUCCESS? 1. *PERCENT OF ORANGE AIRCRAFT DESTROYED* 2. *PERCENT OF OWN CAPABILITY DESTROYED* 3.	Examples may be requested.
A5: YOUR ANSWERS INDICATE THE FOLLOWING HIERARCHY OF OBJECTIVES: SUPERIOR'S OBJECTIVES: 1. PREVENT THE ORANGE ATTACK TASK FORCE OBJECTIVES: 1. NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND OUTCOME MEASURES: 1. PERCENT OF ORANGE AIRCRAFT DESTROYED 2. PERCENT OF OWN CAPABILITY DESTROYED	
IF YOU ACHIEVED DESIRED VALUES FOR EACH OF THESE OUTCOME MEASURES, IS THERE ANY WAY THE MISSION OUTCOME COULD BE UNDESIRABLE? *NO*	Answering "YES" to either of these questions initiates subroutines for refining the list of outcome measures.
IS THERE ANY WAY THE MISSION OUTCOME COULD BE DESIRABLE WITHOUT ACHIEVING THESE VALUES OF THE OUTCOME MEASURE? *NO*	

Table 1 (Continued)

<table>
<tr><th colspan="2">PRELIMINARY STRUCTURING PHASE</th></tr>
<tr><th>User/Terminal Dialog</th><th>Comments, Auxiliary Aid Outputs, Color Monitor Displays</th></tr>
<tr><td>B1: POSITION PLAYING PIECES ON THE SIMULATION BOARD IN ACCORDANCE WITH ASSUMED POSITIONS OF RELEVANT FRIENDLY AND ENEMY FORCES AT THE TIME AT WHICH AN ACTION IS CONTEMPLATED.</td><td>Beginning of the alternative generation function. See Section 2 for an illustration and description of the use of the simulation board.</td></tr>
<tr><td>B2: PREPARE A LIST OF TENTATIVE OWN COURSES OF ACTION WHICH, IF SUCCESSFUL, WILL ACCOMPLISH THE MISSION.
1. MAXIMUM STRENGTH AIR STRIKE WITH REDUCED DEFENSE
2. MEDIUM STRENGTH AIR STRIKE WITH MODERATE DEFENSE
3. MINIMUM STRENGTH AIR STRIKE WITH STRONG DEFENSE
4.</td><td>Examples may be requested.</td></tr>
<tr><td>C1: GIVEN YOUR PRESENT STATE OF KNOWLEDGE, WHICH COURSE OF ACTION APPEARS TO HAVE THE BEST CHANCE FOR SUCCESS? (IDENTIFY BY NUMBER)
2. MEDIUM STRENGTH AIR STRIKE WITH MODERATE DEFENSE</td><td>Beginning of the alternative evaluation function.</td></tr>
<tr><td>C2: ASSUME THE ALTERNATIVE "MEDIUM STRENGTH AIR STRIKE WITH MODERATE DEFENSE." USING THE SIMULATION BOARD:
1. TRACE OUT PLANNED OWN FORCE MOVEMENT AND SIMULATE ENGAGEMENT LOSSES.
2. TRACE OUT ANTICIPATED ENEMY RESPONSE AND SIMULATE ENGAGEMENT LOSSES.
3. REVISE YOUR ACTION PLAN AS NECESSARY IN LIGHT OF SIMULATION RESULTS.</td><td><table><tr><th colspan="3">ESTIMATED LOSSES
(From Simulation Board)</th></tr><tr><th></th><th>Aircraft (squadrons)</th><th>Ships</th></tr><tr><td>Orange</td><td>4xMIG21, 2xSU7</td><td>2xMB</td></tr><tr><td>Blue</td><td>0.5xF14, 0.2xA6, 0.3xA7</td><td></td></tr></table></td></tr>
<tr><td>C3: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "MEDIUM STRENGTH AIR STRIKE WITH MODERATE DEFENSE" UNDER THE ANTICIPATED ENEMY RESPONSE:
1. PERCENT OF ORANGE AIRCRAFT DESTROYED:
40%
2. PERCENT OF OWN CAPABILITY DESTROYED:
1%</td><td></td></tr>
<tr><td>C4: IDENTIFY SCENARIOS THAT MAKE THE ALTERNATIVE "MEDIUM STRENGTH AIR STRIKE WITH MODERATE DEFENSE" LOOK VERY BAD. SELECT THE SCENARIO OF GREATEST CONCERN TO YOU. USING THE SIMULATION BOARD:
1. TRACE OUT ENEMY FORCE MOVEMENT UNDER YOUR WORST-CASE SCENARIO AND ESTIMATE ENGAGEMENT LOSSES.
2. REVISE YOUR ACTION PLAN OR WORST-CASE SCENARIO AS NECESSARY IN LIGHT OF SIMULATION RESULTS.</td><td>Worst-case scenario is attack planes encounter poor visibility at ONRODA plus Red attacks the task force while defense is weakened from offensive use of aircraft.</td></tr>
</table>

Table 1 (Continued)

<table>
<tr><th colspan="2">PRELIMINARY STRUCTURING PHASE</th></tr>
<tr><th>User/Terminal Dialog</th><th>Comments, Auxiliary Aid Outputs, Color Monitor Displays</th></tr>
<tr><td>C5: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "MEDIUM STRENGTH AIR STRIKE WITH MODERATE DEFENSE" UNDER THE WORST-CASE SCENARIO:

1. PERCENT OF ORANGE AIRCRAFT DESTROYED:

25%

2. PERCENT OF OWN CAPABILITY DESTROYED:

15%</td><td><table><tr><th colspan="3">ESTIMATED LOSSES
(From Simulation Board)</th></tr><tr><th></th><th>Aircraft (squadrons)</th><th>Ships</th></tr><tr><td>Orange
Blue</td><td>3xMIG21, 1xSU7
2xF14, 1.5xA6, 1.5xA7</td><td>1xMB
1xDD, 0.3xCG, 0.3xCV</td></tr></table></td></tr>
<tr><td>D1: IF A SIGNIFICANT DIFFERENCE EXISTS BETWEEN THE DESIRABILITY OF TWO SCENARIOS, WHAT EVENT OR EVENTS ARE MOST RESPONSIBLE FOR THE DIFFERENCE?

1. BAD WEATHER AT ONRODA
2. RED ATTACK OF TASK FORCE DURING AIR STRIKE</td><td>Uncertainty identification function.</td></tr>
<tr><td>C1': ARE THERE OTHER ALTERNATIVE COURSES OF ACTION THAT YOU WISH TO EXPLORE? (IDENTIFY BY NUMBER)

1. MAXIMUM STRENGTH AIR STRIKE WITH REDUCED DEFENSE
2. MEDIUM STRENGTH AIR STRIKE WITH MODERATE DEFENSE
3. MINIMUM STRENGTH AIR STRIKE WITH STRONG DEFENSE

3. MINIMUM STRENGTH AIR STRIKE WITH STRONG DEFENSE</td><td>Beginning of the alternative evaluation function.</td></tr>
<tr><td>C2: ASSUME THE ALTERNATIVE "MINIMUM STRENGTH AIR STRIKE WITH STRONG DEFENSE." USING THE SIMULATION BOARD:

1. TRACE OUT PLANNED OWN FORCE MOVEMENT AND SIMULATE ENGAGEMENT LOSSES.

2. TRACE OUT ANTICIPATED ENEMY RESPONSE AND SIMULATE ENGAGEMENT LOSSES.

3. REVISE YOUR ACTION PLAN AS NECESSARY IN LIGHT OF SIMULATION RESULTS.

C3: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "MINIMUM STRENGTH AIR STRIKE WITH STRONG DEFENSE" UNDER THE ANTICIPATED ENEMY RESPONSE:

1. PERCENT OF ORANGE AIRCRAFT DESTROYED:

25%

2. PERCENT OF OWN CAPABILITY DESTROYED:

1%</td><td><table><tr><th colspan="3">ESTIMATED LOSSES
(From Simulation Board)</th></tr><tr><th></th><th>Aircraft (squadrons)</th><th>Ships</th></tr><tr><td>Orange
Blue</td><td>3xMIG21, 2xSU7
0.6xF14, 0.2xA6, 0.4xA7</td><td>1xMB</td></tr></table></td></tr>
</table>

Table 1 (Continued)

<table>
<tr><th colspan="2">PRELIMINARY STRUCTURING PHASE</th></tr>
<tr><th>User/Terminal Dialog</th><th>Comments, Auxiliary Aid Outputs, Color Monitor Displays</th></tr>
<tr><td>C4: TAKING THE POINT OF VIEW OF AN ENEMY COMMANDER, IDENTIFY SCENARIOS THAT MAKE THE ALTERNATIVE "MINIMUM STRENGTH AIR STRIKE WITH STRONG DEFENSE" LOOK VERY BAD. SELECT THE SCENARIO OF GREATEST CONCERN TO YOU. USING THE SIMULATION BOARD:

1. TRACE OUT ENEMY FORCE MOVEMENTS UNDER YOUR WORST-CASE SCENARIO AND ESTIMATE ENGAGEMENT LOSSES.

2. REVISE YOUR ACTION PLAN OR WORST-CASE SCENARIO AS NECESSARY IN LIGHT OF SIMULATION RESULTS.</td><td>Worst-case scenario is, again, attack planes encounter poor visibility plus Red attacks the task force.

<table><tr><th colspan="3">ESTIMATED LOSSES
(From Simulation Board)</th></tr><tr><th></th><th>Aircraft (squadrons)</th><th>Ships</th></tr><tr><td>Orange</td><td>2.5xMIG21, 1xSU7</td><td>1xMB</td></tr><tr><td>Blue</td><td>1.3xF14, 1.5xA6, 1.5xA7</td><td>1xDD, 0.2xCG, 0.1xCV</td></tr></table></td></tr>
<tr><td>C5: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "MINIMUM STRENGTH AIR STRIKE WITH STRONG DEFENSE" UNDER THE WORST-CASE SCENARIO:

1. PERCENT OF ORANGE AIRCRAFT DESTROYED:

15%

2. PERCENT OF OWN CAPABILITY DESTROYED:

8%</td><td></td></tr>
<tr><td>D1: IF A SIGNIFICANT DIFFERENCE EXISTS BETWEEN THE DESIRABILITY OF THE TWO SCENARIOS, WHAT EVENT OR EVENTS ARE MOST RESPONSIBLE FOR THE DIFFERENCE?

1. BAD WEATHER AT ONRODA
2. RED ATTACK OF TASK FORCE DURING AIR STRIKE</td><td>Uncertainty identification function.</td></tr>
<tr><td>E1: SELECT AN ACTION FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW TASK INCENTIVE
2. REVIEW OBJECTIVES AND OUTCOME MEASURES
3. REVIEW LIST OF ALTERNATIVES
4. REVIEW EVALUATION OF ALTERNATIVES
5. TERMINATE PRELIMINARY STRUCTURING PHASE

5</td><td>End of the preliminary structuring phase.</td></tr>
</table>

Table 1 (Continued)

MODELING PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
A1: DO YOU WISH TO REVIEW THE RESULTS OF THE PRELIMINARY STRUCTURING PHASE?	
NO	
B1: PROVIDE A LABEL FOR THE PRIMARY DECISION UNDER CONSIDERATION. (ONLY THE FIRST 9 CHARACTERS OF LABELS APPEAR IN DISPLAYS.)	Beginning of the influence diagram construction.
PRIMARY DECISION: *ATK PLAN*	
B2: PROVIDE LABELS FOR EACH DOWN-STREAM DECISION THAT YOU WOULD LIKE TO APPEAR IN THE INFLUENCE DIAGRAM.	
DOWN-STREAM DECISION 1:	
B3: PROVIDE A LABEL FOR EACH CRITICAL UNCERTAINTY THAT YOU WOULD LIKE TO APPEAR IN THE INFLUENCE DIAGRAM.	
CRITICAL UNCERTAINTY 1: *WEATHER* CRITICAL UNCERTAINTY 2: *RED ACT* CRITICAL UNCERTAINTY 3:	
B4: OUTCOME MEASURES AVAILABLE IN THE VALUE MODEL ARE:	
1. NUMBER OF POTENTIAL ORANGE SORTIES AGAINST GREY DURING THE NEXT 12 WEEK PERIOD (SORTIES)	
2. PROBABILITY THAT BLUE AND RED WILL DECLARE WAR DURING THE NEXT 12 WEEK PERIOD (PROB WAR)	
3. FRACTION OF BLUE CARRIER AND CRUISER CAPABILITY DESTROYED (SHIP LOSS)	
4. NUMBER AND TYPE OF BLUE FIGHTER AND ATTACK AIRCRAFT DESTROYED (AIR LOSS)	
5. PERCENT OF ORANGE AIRCRAFT ON ONRODA DESTROYED (% KILLED)	
6. PERCENT OF TASK FORCE CAPABILITY DESTROYED (OWN LOSS)	
INDICATE BY NUMBER THE OUTCOME MEASURES THAT YOU WOULD LIKE TO APPEAR IN THE INFLUENCE DIAGRAM.	
5, 6	
OUTCOME MEASURES WILL BE:	
1. % KILLED 2. OWN LOSS	

Table 1 (Continued)

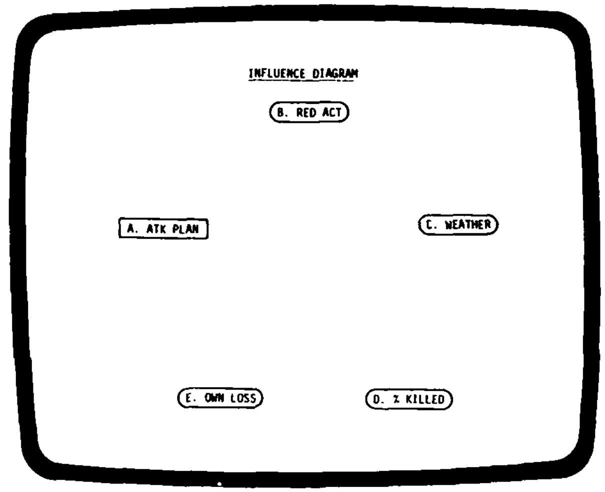
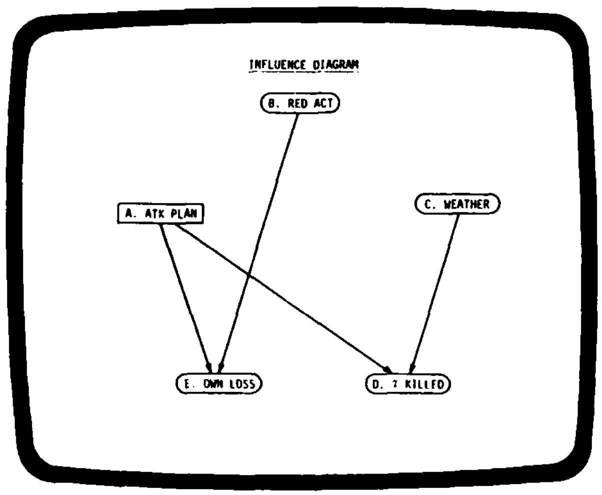
MODELING PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
B5: DECISIONS, CRITICAL UNCERTAINTIES, AND OUTCOME MEASURES ARE REPRESENTED BY THE VARIABLES SHOWN IN THE DISPLAY. SPECIFY THE INFLUENCES AMONG THESE VARIABLES. *A → D, E; B → E; C → D* C1: PROVIDE A LABEL FOR EACH ALTERNATIVE UNDER CONSIDERATION FOR THE DECISION "ATK PLAN". ALTERNATIVE 1: *MOD A/S* ALTERNATIVE 2: *MIN A/S* ALTERNATIVE 3: C2: PROVIDE A LABEL AND PROBABILITY FOR EACH POSSIBLE OUTCOME TO THE UNCERTAINTY LISTED BELOW UNDER EACH ASSUMPTION. A BLANK LABEL WILL INDICATE THAT ALL OUTCOMES HAVE BEEN SPECIFIED. POSSIBLE OUTCOMES FOR "WEATHER": OUTCOME 1: *CLEAR* PROBABILITY: *.6* OUTCOME 2: *RAIN* PROBABILITY: *.4* OUTCOME 3: POSSIBLE OUTCOMES FOR THE UNCERTAINTY "RED ACT": OUTCOME 1: *RED ATK* PROBABILITY: *.1* OUTCOME 2: *NO RED AT* PROBABILITY: *.9* OUTCOME 3:	 

Table 1 (Continued)

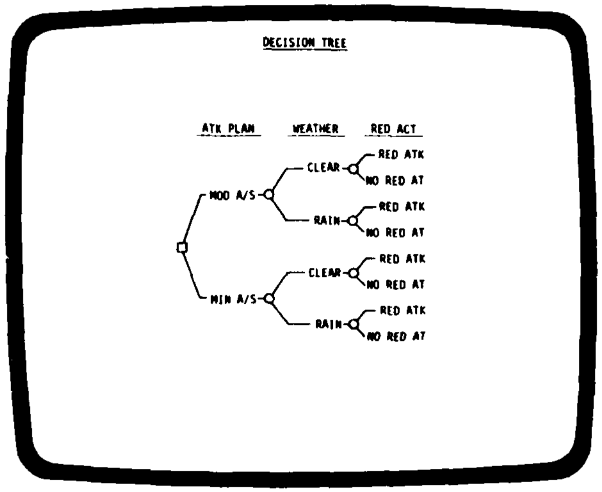
MODELING PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
C3: EACH PATH THROUGH THE DECISION TREE CORRESPONDS TO A SCENARIO. ENTER YOUR BEST, LOW AND HIGH ESTIMATES FOR THE EXPECTED VALUES OF EACH OUTCOME MEASURE UNDER EACH SCENARIO. IF YOUR ESTIMATES FOR A GIVEN SCENARIO ARE THE SAME AS SPECIFIED IN A PREVIOUS SCENARIO, TYPE "USE X", WHERE X IS THE NUMBER OF THE PREVIOUS SCENARIO. SCENARIO 1: "ATK PLAN" = "MOD A/S" "WEATHER" = "CLEAR" "RED ACT" = "RED ATK" A. "% KILLED" (BEST, LOW, HIGH EST.): *40, 15, 60* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *15, 10, 28* SCENARIO 2: "ATK PLAN" = "MOD A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" A. "% KILLED" (BEST, LOW, HIGH EST.): 40, 15, 60 (Y/N?) *Y* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *1, .5, 7* SCENARIO 3: "ATK PLAN" = "MOD A/S" "WEATHER" = "RAIN" "RED ACT" = "RED ATK" A. "% KILLED" (BEST, LOW, HIGH EST.): *20, 10, 40* B. "OWN LOSS" (BEST, LOW, HIGH EST.): 15, 10, 28 (Y/N?) *Y* SCENARIO 4: "ATK PLAN" = "MOD A/S" "WEATHER" = "RAIN" "RED ACT" = "NO RED AT" A. "% KILLED" (BEST, LOW, HIGH EST.): 20, 10, 40 (Y/N?) *Y* B. "OWN LOSS" (BEST, LOW, HIGH EST.): 1, .5, 7 (Y/N?) *Y* SCENARIO 5: "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "RED ATK" A. "% KILLED" (BEST, LOW, HIGH EST.): *25, 20, 50* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *8, 5, 12* SCENARIO 6: "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" A. "% KILLED" (BEST, LOW, HIGH EST.): 25, 10, 50 (Y/N?) *Y* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *1, .5, 3*	

Table 1 (Continued)

<table>
<tr><th colspan="2">MODELING PHASE</th></tr>
<tr><th>User/Terminal Dialog</th><th>Comments, Auxiliary Aid Outputs, Color Monitor Displays</th></tr>
<tr><td>
SCENARIO 7: "ATK PLAN" = "MIN A/S"
"WEATHER" = "RAIN"
"RED ACT" = "RED ATK"

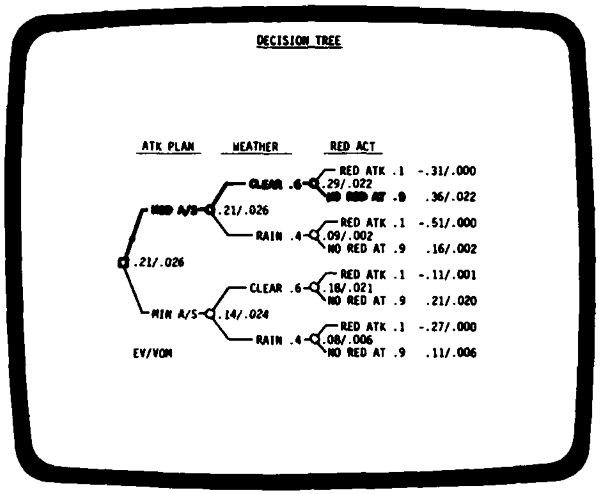
A. "% KILLED" (BEST, LOW, HIGH EST.): *15, 5, 35*
B. "OWN LOSS" (BEST, LOW, HIGH EST.): 8, 5, 12 (Y/N?) *Y*

SCENARIO 8: "ATK PLAN" = "MIN A/S"
"WEATHER" = "RAIN"
"RED ACT" = "NO RED AT"

A. "% KILLED" (BEST, LOW, HIGH EST.): 15, 5, 35 (Y/N?) *Y*
B. "OWN LOSS" (BEST, LOW, HIGH EST.): 1, .5, 3 (Y/N?) *Y*

D1: SELECT AN ITEM FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW INFLUENCE DIAGRAM
2. REVIEW DECISION TREE
3. REVIEW OUTCOME MEASURE ESTIMATES
4. TERMINATE MODELING PHASE

4
</td><td>


(Color monitor shows initial decision tree, strategy maximizing expected value. and path with highest value of further modeling.)

End of the modeling phase.
</td></tr>
</table>

Table 1 (Continued)

EXPANSION PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
A1: DO YOU WISH TO REVIEW THE RESULTS OF THE MODELING PHASE?	
NO	
B1: SUPPOSE YOU CHOOSE THE ALTERNATIVE "MOD A/S" AND THE EVENTS "CLEAR" AND "NO RED AT" OCCUR. IS THERE ANY EVENT NOT YET INCLUDED IN THE MODEL THAT COULD CAUSE "OWN LOSS" TO INCREASE? (A VALUE OF 11 WOULD BE SUFFICIENT TO PRODUCE A DECISION SWITCH.)	Beginning of the event identification function. Attention is focused on the outcome variable OWN LOSS because sensitivity analysis indicates uncertainty on this variable is the major contributor to the high value of modeling along the path MOD A/S followed by NO RED AT.
YES	
B2: DESCRIBE THE EVENT AND PROVIDE A LABEL FOR IT. (ONLY THE FIRST 9 CHARACTERS OF LABELS APPEAR IN DISPLAYS.) EVENT DESCRIPTION: *ORANGE PREEMPTIVE ATTACK ON TASK FORCE* EVENT LABEL: *ORNGE ATK*	
C1: IF YOU KNEW FOR SURE THE EVENT "ORNGE ATK" WOULD OCCUR, WOULD YOU LIKELY PREFER SOME ALTERNATIVE OTHER THAN "MOD A/S"?	Beginning of the event testing function.
YES	
C2: WHICH OF THE FOLLOWING SCENARIOS MIGHT BE SIGNIFICANTLY AFFECTED BY THE EVENT "ORNGE ATK"? (INDICATE BY NUMBER) 1. SCENARIO 1: "ATK PLAN" = "MOD A/S" "WEATHER" = "CLEAR" "RED ACT" = "RED ATK" 2. SCENARIO 2: "ATK PLAN" = "MOD A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" 3. SCENARIO 3: "ATK PLAN" = "MOD A/S" "WEATHER" = "RAIN" "RED ACT" = "RED ATK" 4. SCENARIO 4: "ATK PLAN" = "MOD A/S" "WEATHER" = "RAIN" "RED ACT" = "NO RED AT" 5. SCENARIO 5: "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "RED ATK" 6. SCENARIO 6: "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT"	Preliminary inquiries designed to reduce input requirements for event testing.

Table 1 (Continued)

EXPANSION PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
7. SCENARIO 7: "ATK PLAN" = "MIN A/S" "WEATHER" = "RAIN" "RED ACT" = "RED ATK" 8. SCENARIO 8: "ATK PLAN" = "MIN A/S" "WEATHER" = "RAIN" "RED ACT" = "NO RED AT" *2, 4, 6, 8* WHICH OUTCOME MEASURES MIGHT BE SIGNIFICANTLY AFFECTED BY THE EVENT "ORNGE ATK"? (INDICATE BY NUMBER) 1. "% KILLED" 2. "OWN LOSS" *2* ROUGHLY, WHAT IS THE PROBABILITY OF THE EVENT "ORNGE ATK"? *.3*	
IF YOU KNEW FOR CERTAIN THE EVENT "ORNGE ATK" WOULD OCCUR, INDICATE HOW YOUR ESTIMATES OF THE OUTCOME MEASURE WOULD CHANGE UNDER EACH SCENARIO. (INDICATE BY NUMBER) SCENARIO 2: "ATK PLAN" = "MOD A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" THE CURRENT ESTIMATE FOR "OWN LOSS" IS: 1 IF THE EVENT "ORNGE ATK" OCCURS, THE VALUE WOULD BE: 1. MUCH LOWER (LESS THAN .5) 2. LOWER (BETWEEN .5 AND .8) 3. ABOUT THE SAME (BETWEEN .8 AND 2.2) 4. HIGHER (BETWEEN 2.2 AND 7) 5. MUCH HIGHER (ABOVE 7) *5*	Event testing.

Table 1 (Continued)

EXPANSION PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
SCENARIO 4: "ATK PLAN" = "MOD A/S" "WEATHER" = "RAIN" "RED ACT" = "NO RED AT" THE CURRENT ESTIMATE FOR "AIR LOSS" IS: 1 IF THE EVENT "ORNGE ATK" OCCURS, THE VALUE WOULD BE: 1. MUCH LOWER (LESS THAN .5) 2. LOWER (BETWEEN .5 AND .8) 3. ABOUT THE SAME (BETWEEN .8 AND 2.2) 4. HIGHER (BETWEEN 2.2 AND 7) 5. MUCH HIGHER (ABOVE 7) 5 SCENARIO 6: "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" THE CURRENT ESTIMATE FOR "AIR LOSS" IS: 1 IF THE EVENT "ORNGE ATK" OCCURS, THE VALUE WOULD BE: 1. MUCH LOWER (LESS THAN .5) 2. LOWER (BETWEEN .5 AND .8) 3. ABOUT THE SAME (BETWEEN .8 AND 1.4) 4. HIGHER (BETWEEN 1.4 AND 3) 5. MUCH HIGHER (ABOVE 3) 4 SCENARIO 8: "ATK PLAN" = "MIN A/S" "WEATHER" = "RAIN" "RED ACT" = "NO RED AT" THE CURRENT ESTIMATE FOR "AIR LOSS" IS: 30 IF THE EVENT "ORNGE ATK" OCCURS, THE VALUE WOULD BE: 1. MUCH LOWER (LESS THAN .5) 2. LOWER (BETWEEN .5 AND .8) 3. ABOUT THE SAME (BETWEEN .8 AND 1.4) 4. HIGHER (BETWEEN 1.4 AND 3) 5. MUCH HIGHER (ABOVE 3) 4	

Table 1 (Continued)

EXPANSION PHASE

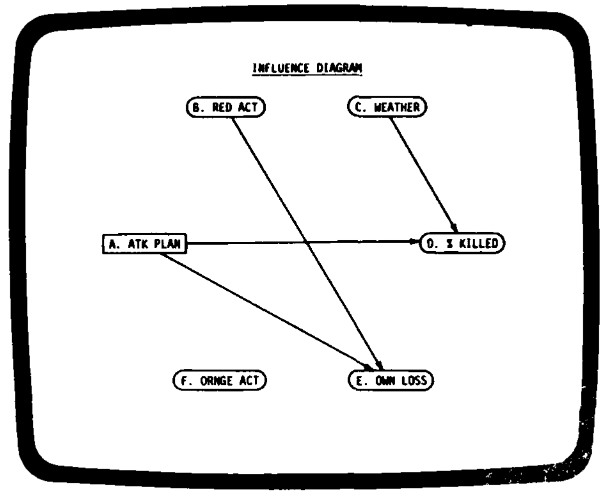
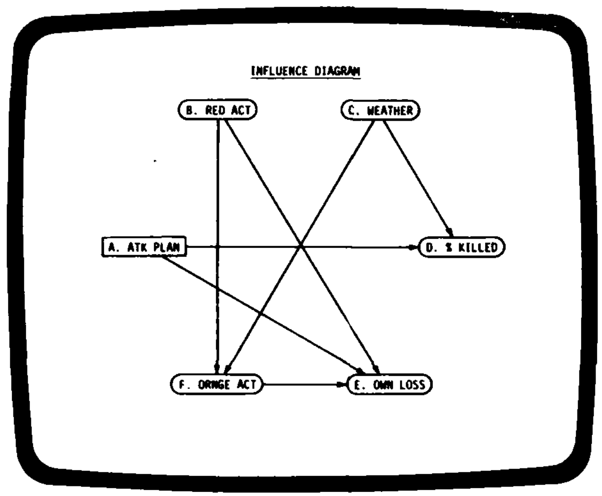
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
C3: ANALYSIS INDICATES THAT RELIABILITY OF THE DECISION MODEL WILL BE IMPROVED IF THE DECISION TREE IS EXPANDED TO INCLUDE THE NEW EVENT. D1: PROVIDE A LABEL FOR EACH NEW CRITICAL UNCERTAINTY THAT YOU WOULD LIKE TO BE ADDED TO THE INFLUENCE DIAGRAM. CRITICAL UNCERTAINTY 1: *ORNGE ACT* CRITICAL UNCERTAINTY 2: D2: PROVIDE LABELS FOR EACH DOWN-STREAM DECISION THAT YOU WOULD LIKE TO BE ADDED TO THE INFLUENCE DIAGRAM. DOWN-STREAM DECISION 1: D3: SPECIFY THE INFLUENCES BETWEEN THE NEW VARIABLES AND THE VARIABLES IN THE EXISTING INFLUENCE DIAGRAM. *B → F; C → F; F → E* D4: *PROVIDE A LABEL AND PROBABILITY FOR EACH POSSIBLE OUTCOME TO THE* UNCERTAINTY LISTED BELOW UNDER EACH ASSUMPTION. A BLANK LABEL WILL INDICATE THAT ALL OUTCOMES HAVE BEEN SPECIFIED. ASSUMPTION: "WEATHER" = "CLEAR" "RED ACT" = "RED ATK" POSSIBLE OUTCOMES FOR THE UNCERTAINTY "ORNGE ACT" OUTCOME 1: *ORNGE ATK* PROBABILITY: *1* OUTCOME 2: ASSUMPTION: "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" POSSIBLE OUTCOMES FOR THE UNCERTAINTY "ORNGE ACT" OUTCOME 1: *ORNGE ATK* PROBABILITY: *.3* OUTCOME 2: *NO ORN AT* PROBABILITY: *.7* OUTCOME 3:	 

Table 1 (Continued)

EXPANSION PHASE

User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays

ASSUMPTION: "WEATHER" = "RAIN"
"RED ACT" = "RED ATK"

POSSIBLE OUTCOMES FOR THE UNCERTAINTY "ORNGE ACT"

OUTCOME 1: *ORNGE ATK*
PROBABILITY: *1*

OUTCOME 2:

ASSUMPTION: "WEATHER" = "CLEAR"
"RED ACT" = "NO RED AT"

POSSIBLE OUTCOMES FOR THE UNCERTAINTY "ORNGE ACT"

OUTCOME 1: *NO ORNGE AT*
PROBABILITY: *1*

OUTCOME 2:

D5: DO YOU WISH TO REVIEW PREVIOUS OUTCOME ESTIMATES BEFORE UPDATING THESE ESTIMATES?

NO

D6: EACH PATH THROUGH THE DECISION TREE CORRESPONDS TO A SCENARIO. ENTER YOUR BEST, LOW AND HIGH ESTIMATES FOR THE EXPECTED VALUES OF EACH OUTCOME MEASURE UNDER EACH SCENARIO. IF YOUR ESTIMATES FOR A GIVEN SCENARIO ARE THE SAME AS SPECIFIED IN A PREVIOUS SCENARIO, TYPE "USE X", WHERE X IS THE NUMBER OF THE PREVIOUS SCENARIO.

SCENARIO 1': "ATK PLAN" = "MOD A/S"
"WEATHER" = "CLEAR"
"RED ACT" = "RED ATK"
"ORNGE ACT" = "ORNGE ATK"

A. "% KILLED" (BEST, LOW, HIGH EST.): *35, 12, 50*
B. "OWN LOSS" (BEST, LOW, HIGH EST.): *20, 12, 30*

SCENARIO 2': "ATK PLAN" = "MOD A/S"
"WEATHER" = "CLEAR"
"RED ACT" = "NO RED AT"
"ORNGE ACT" = "ORNGE ATK"

A. "% KILLED" (BEST, LOW, HIGH EST.): 35, 12, 50 (Y/N?) *Y*
B. "OWN LOSS" (BEST, LOW, HIGH EST.): *8, 5, 14*

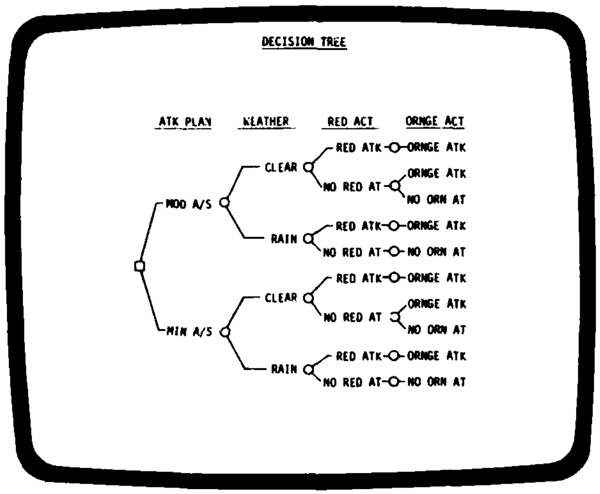


Table 1 (Continued)

EXPANSION PHASE	
User/Terminal Dialog	Comments, Auxiliary Aid Outputs, Color Monitor Displays
SCENARIO 3': "ATK PLAN" = "MOD A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" "ORNGE ACT" = "NO ORN AT" A. "% KILLED" (BEST, LOW, HIGH EST.): *USE 2* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *USE 2* SCENARIO 4': "ATK PLAN" = "MOD A/S" "WEATHER" = "RAIN" "RED ACT" = "RED ATK" "ORNGE ACT" = "ORNGE ATK" A. "% KILLED" (BEST, LOW, HIGH EST.): *15, 5, 35* B. "OWN LOSS" (BEST, LOW, HIGH EST.): 20, 12, 30 (Y/N?) *Y* SCENARIO 5': "ATK PLAN" = "MOD A/S" "WEATHER" = "RAIN" "RED ACT" = "NO RED AT" "ORNGE ACT" = "NO ORN AT" A. "% KILLED" (BEST, LOW, HIGH EST.): *USE 4* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *USE 4* SCENARIO 6': "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "RED ATK" "ORNGE ACT" = "ORNGE ATK" A. "% KILLED" (BEST, LOW, HIGH EST.): *20, 8, 45* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *15, 10, 25* SCENARIO 7': "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" "ORNGE ACT" = "ORNGE ATK" A. "% KILLED" (BEST, LOW, HIGH EST.): 25, 9, 45 (Y/N?) *Y* B. "OWN LOSS" (BEST, LOW, HGIH EST.): *6, 3, 8* SCENARIO 8': "ATK PLAN" = "MIN A/S" "WEATHER" = "CLEAR" "RED ACT" = "NO RED AT" "ORNGE ACT" = "NO ORN AT" A. "% KILLED" (BEST, LOW, HIGH EST.): *USE 6* B. "OWN LOSS" (BEST, LOW, HIGH EST.): *USE 6*	

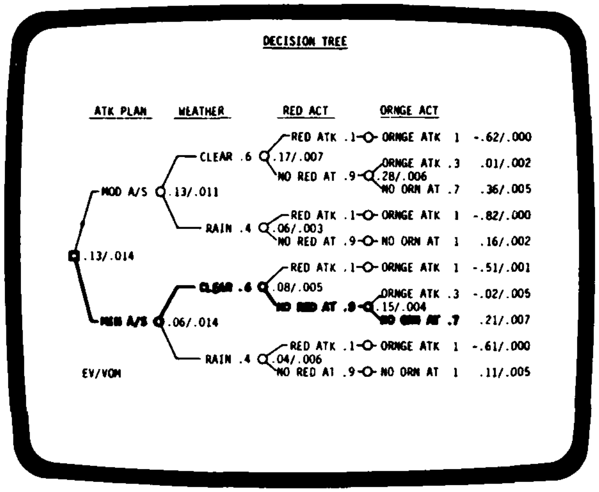
Table 1 (Continued)

EXPANSION PHASE

User/Terminal Dialog

```
SCENARIO 9':  "ATK PLAN"   = "MIN A/S"
              "WEATHER"    = "RAIN"
              "RED ACT"    = "RED ATK"
              "ORNGE ACT"  = "ORNGE ATK"

   A.  "% KILLED" (BEST, LOW, HIGH EST.):  10, 5, 30
   B.  "OWN LOSS" (BEST, LOW, HIGH EST.):  15, 10, 25 (Y/N?) Y

SCENARIO 10': "ATK PLAN"   = "MIN A/S"
              "WEATHER"    = "RAIN"
              "RED ACT"    = "NO RED AT"
              "ORNGE ACT"  = "NO ORN AT"

   A.  "% KILLED" (BEST, LOW, HIGH EST.):  USE 8
   B.  "OWN LOSS" (BEST, LOW, HIGH EST.):  USE 8

E1:  SELECT AN ITEM FROM THE MENU (INDICATE BY NUMBER):

   1.  REVIEW INFLUENCE DIAGRAM
   2.  REVIEW DECISION TREE
   3.  REVIEW OUTCOME MEASURE ESTIMATES
   4.  CONTINUE EXPANSION
   5.  TERMINATE EXPANSION PHASE

5
```

Comments, Auxiliary Aid Outputs, Color Monitor Displays



(Color monitor shows expanded decision tree strategy maximizing expected value and path with highest value of further modeling.)

End of the expansion phase.

Section 3 gives a more detailed illustrative application and provides a running explanation.

2.4 Computer Program Characteristics and Current Status

The interactive computer programs for applying the decision structuring process are written in the APL language. Each component of the aid (Program for Systematic Inquiry, Program for Influence Diagram and Decision Tree Construction, and Program for Decision Tree Expansion and Analysis) can be accessed independently. Operating instructions are given in Appendix B.

Programs were designed for execution at the ODA/University of Pennsylvania test-bed, with graphics hardware consisting of a Grinnel (for displaying decision trees and influence diagrams) and a CONAPL (for interactive dialogue) (Figure 9). Much of the develoment was conducted through remote access from SRI International Menlo Park offices (over the ARPANET) using a Ramtek 6800 for graphics and a Datamedia for dialogue (Figure 10). As currently implemented, the aid requires approximately 40,000 bytes of memory for execution. The software is capable of communicating with virtually any standard video display terminal in place of the CONAPL or Datamedia. Modifications would be required to substitute another color graphics terminal for the Grinnel or Ramtek because each graphics terminal has its own unique set of commands for producing images on the screen.

Because the aid normally will be run in a time-sharing computer environment, speed of execution is strongly affected by other demands being made on the host computer. Optimal performance is obtained by using higher speed access lines when the aid is being used from a remote site. High speed is a desirable feature to prevent delays during the construction of diagrams on the color monitors. The cost of using the aid as it was implemented on the test-bed averaged approximately $30/hour.

In May 1981, support of the ODA test-bed was discontinued by the Office of Naval Research. As a result, access of the structuring aid may not currently be possible. Software for the aid has been saved on machine-readable medium and could be loaded onto another host computer; however, this would require some modifications to the software to accommodate the nonstandardized APL usage made necessary by the host implementation of the APL language.

3. DESCRIPTION AND DETAILED ILLUSTRATIVE APPLICATION OF THE COMPUTER-AIDED STRUCTURING PROCESS

The purpose of this section is to present a detailed description and illustration of the computer-aided decision structuring process. Format and wording of queries, information requests, and computer outputs as they exist in the current implementation are presented. To better illustrate the use of the aid in the structuring process, an extended example is used. Although the user input provided in the example is hypothetical, the example is essentially a compilation of informal test applications performed during development of the aid. For these applications, subjects were asked to review the ONRODA Warfare Scenario and select a decision for structuring.*

---

*The ONRODA Warfare Scenario [13] is a hypothetical Navy strike warfare scenario developed by the SRI Naval Warfare Research Center. It provides detailed parameters describing credible forces, geography, environment, and other pertinent factors for task force decision-making. The purpose of the scenario was to support the various ODA contractors in the development and simulated use of their decision aids.

<u>Synopsis</u>

The scenario principally concerns four countries: Blue, Red, Grey, and Orange. Blue is alligned with Grey. Red is alligned with Orange. ONRODA is an island territory of Grey. Blue has two carrier groups in the area. Red has a number of warships nearby. Grey and Orange have been ideologically opposed and hostile toward one another for some time, but a significant segment of ONRODA's population are Orange sympathizers. A rebellion begins in Grey, and Orange responds by capturing ONRODA Island and providing active support of the "Grey-hawk" rebels. Blue has historically indicated that aggressive action by Orange into the internal affairs of Grey would be unacceptable and has asked its congress to approve unilateral support of grey if UN action is not immediate. Simultaneously, Blue forms a carrier task force and provides the following mission directive, "When directed, begin operations to neutralize Orange forces and facilities on ONRODA Island in order to defend Grey. Do not attack targets on Orange mainland or in Orange ports. Take defensive measures to protect your force from Orange or Red retaliations."

Most subjects selected the TFC's planning decision.

Three type faces are used to help the reader's understanding. Instructions, requests for data, and other information presented by the computer are shown in bold face as they appear on the video screen or terminal printout. User inputs are shown in italic. Everything else, including comments and descriptions, are in the type face of this introduction. The process is presented according to its 3 basic phases--preliminary structuring, modeling, and expansion--with a subsection devoted to each. Within each subsection, a separate subsection is used to present each function, or individual step, of the process.

3.1 Preliminary Structuring Phase

The preliminary structuring process is an elicitation procedure designed to organize relevant factors of the decision problem and to identify and focus attention on the most important issues. Although a formal decision model is not constructed in this phase, concepts and methods of decision analysis are applied to develop a structured statement of the decision problem. Figure 19 is a flowchart showing the specific preliminary structuring functions and the order in which they are executed. The content of each function and, more generally, the overall approach are designed to quickly produce results applicable to the formation of a decision strategy, minimize input requirements, encourage a more objective understanding of the situation by countering several recognized decision-making errors and biases, and provide output that is consistent with the requirements of the modeling phase.

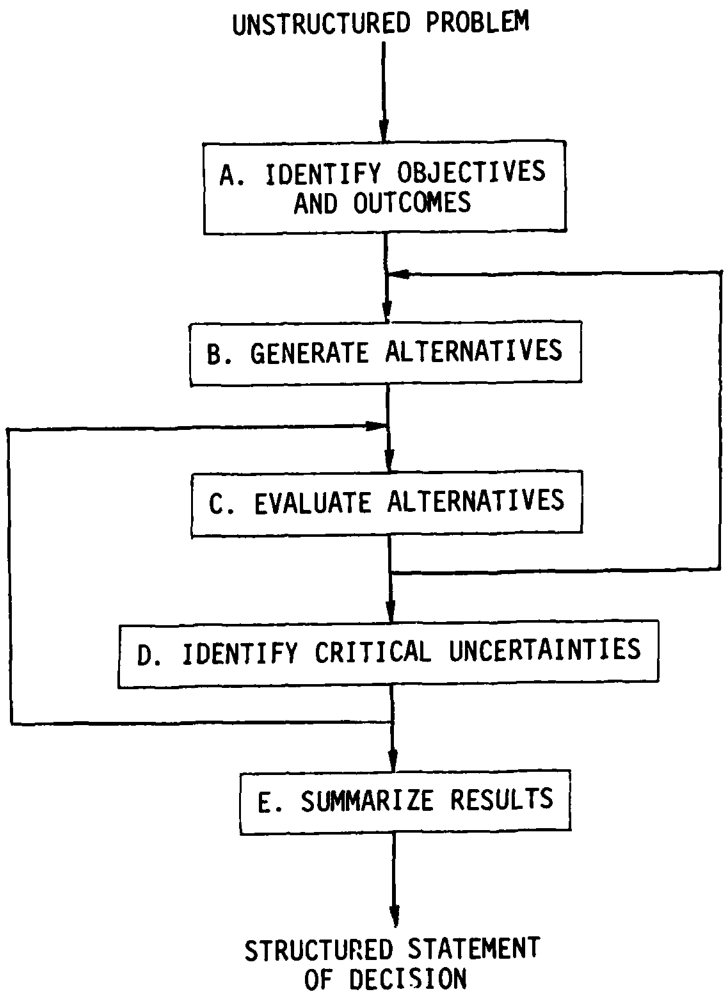


FIGURE 19 FUNCTIONS IN THE PRELIMINARY STRUCTURING PHASE

3.1.1 Objectives and Outcome Identification

The first function to be executed in the preliminary structuring process is to identify the objectives of the decision and an appropriate set of outcome variables. Hence, the principal outputs of this function are a list of decision objectives and associated outcome variables.

Focusing initially on objectives creates the proper decision perspective and counters a common tendency to overlook classes of alternatives by focusing too quickly on just one way to accomplish the mission. The context is first established by reviewing the incentive for the decision and by relating the decision to the broader objectives of the commander's superiors.

A1: WHAT IS THE INCENTIVE OR REASON FOR THE ASSIGNED TASK?

ONRODA HAS BEEN ATTACKED AND OCCUPIED BY ENEMY ORANGE. SURVIVAL OF GREY GOVERNMENT THREATENED BY FURTHER ORANGE AGGRESSION.

A2: WHAT ARE YOUR SUPERIOR'S OBJECTIVES?

1. *SUPPORT GREY IN ITS EFFORTS TO DEFEAT THE REBEL GREYHAWKS AND TO RESIST AN INVASION BY ORANGE.*
2.

In situations where the program is expecting a list of inputs, such as above, the user signifies that his input is complete by typing a carriage return.

Having established the context for the decision, the user is now asked to state a complete set of objectives. Objectives include not only physical objectives, such as a target, but also political, economic, and other relevant military objectives as well.

A3: WHAT IS THE OBJECTIVE OF THE MISSION? IF THE MISSION HAS MULTIPLE OBJECTIVES, LIST THEM.

1. *NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND*
2.

In this example, the user has defined his objectives too narrowly by omitting several key objectives that may be inferred from the fleet directive in the ONRODA scenario. For example, the commander is specifically cautioned to avoid direct conflict with Red. Tests will be applied below to ensure that omissions do not adversely affect results.

The next step is to create a list of outcome measures for assessing the degree to which the decision outcome achieves each objective. These measures will be a basis for selecting outcome variables for the formal decision model to be constructed in the later phases of the structuring process. The outcome measures should be quantifiable--quantities whose values may be expressed by numbers. Defining outcome measures in the preliminary structuring phase helps clarify decision objectives.

A4: WHAT SPECIFIC, QUANTITATIVE MEASURES COULD BE USED TO INDICATE THE DEGREE OF MISSION SUCCESS?

1. *NUMBER AND TYPE OF GREY UNITS DESTROYED*
2. *NUMBER AND TYPE OF ORANGE AIRCRAFT DESTROYED*
3.

If the user indicates he is having trouble with this question (i.e., if he types *HELP*), the program presents a "template" of possible outcome measures:

3. *HELP*

A4.1: THE FOLLOWING ARE OUTCOME MEASURES THAT MAY BE IMPORTANT FOR JUDGING THE SUCCESS OF NAVAL TASK FORCE MISSIONS:

1. TIME REQUIRED TO COMPLETE MISSION
2. NUMBER AND TYPE OF ENEMY UNITS DAMAGED OR DESTROYED
3. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED
4. PERCENT REDUCTION IN OWN CAPABILITY
5. PERCENT REDUCTION IN ENEMY CAPABILITY
6. NUMBER OF ALLIES PUBLICLY EXPRESSING SUPPORT

DO YOU WISH TO ADD ANY OF THESE OR OTHERS TO YOUR LIST OF OUTCOME MEASURES? IF SO, WHAT ARE THE ADDITIONAL OUTCOME MEASURES?

1. *NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED*
2.

Outcome measures, in this example, now reflect the competing goals of neutralizing Orange while avoiding own force losses, but the list is still incomplete. The program now summarizes the objective structure and asks the user to explicitly consider whether there are additional attributes relevant to the decision that have not yet been represented by *outcome measures*.

A5: YOUR ANSWERS INDICATE THE FOLLOWING HIERARCHY OF OBJECTIVES

SUPERIOR'S OBJECTIVES:

1. SUPPORT GREY IN ITS EFFORTS TO DEFEAT THE REBEL GREYHAWKS AND TO RESIST AN INVASION BY ORANGE

TASK FORCE OBJECTIVES:

1. NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND

OUTCOME MEASURES:

1. NUMBER AND TYPE OF GREY UNITS DESTROYED
2. NUMBER AND TYPE OF ORANGE AIRCRAFT DESTROYED
3. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED

IF YOU ACHIEVED DESIRED VALUES FOR EACH OF THESE OUTCOME MEASURES, IS THERE ANY WAY THE MISSION OUTCOME COULD BE UNDESIRABLE?

YES

In answering this question, the user must ask whether there is any way that an outcome with low Grey losses, high Orange aircraft losses, and low Blue losses could be undesirable. The user answered "yes"--reasoning that an outcome that produces a war or high probability of war with Red would be bad, regardless of the outcome of the specific conflict between Orange and Grey. Because the user has indicated that the current list of outcome measures does not fully characterize the essential features for measuring the success of the mission, the computer elicits additional outcome measures.

WHAT OUTCOME MEASURES MUST BE ADDED TO ACCOUNT FOR THIS ASPECT OF THE OUTCOME?

1. *PROBABILITY OF BLUE/RED WAR*
2.

Newly identified outcome measures are added to the objective and outcome measure summary list, and the testing of the measures continues. Since too many outcome measures significantly complicates the model, outcome measures are tested to see if each is necessary.

A5: YOUR ANSWERS INDICATE THE FOLLOWING HIERARCHY OF OBJECTIVES

SUPERIOR'S OBJECTIVES:

1. SUPPORT GREY IN ITS EFFORTS TO DEFEAT THE REBEL GREYHAWKS AND TO RESIST AN INVASION BY ORANGE.

TASK FORCE OBJECTIVES:

1. NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND

OUTCOME MEASURES:

1. NUMBER AND TYPE OF GREY UNITS DESTROYED
2. NUMBER AND TYPE OF ORANGE AIRCRAFT DESTROYED
3. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED
4. PROBABILITY OF BLUE/RED WAR

IF YOU ACHIEVED DESIRED VALUES FOR EACH OF THESE OUTCOME MEASURES, IS THERE ANY WAY THE MISSION OUTCOME COULD BE UNDESIRABLE?

NO

IS THERE ANY WAY THE MISSION OUTCOME COULD BE DESIRABLE WITHOUT ACHIEVING THESE VALUES OF THE OUTCOME MEASURES?

YES

In answering yes, the user reasoned that his mission is to neutralize the Orange aircraft, not necessarily destroy them. Grey might be protected, for example, by convincing Orange not to attack through making it apparent that the effectiveness of an attack or the consequences would be very undesirable for Orange. The user is asked to identify the nonessential outcome measure and to redefine the measure to more accurately reflect his true objectives.

WHICH OUTCOME MEASURE IS NOT ESSENTIAL TO THE SUCCESS OF THE MISSION? (IDENTIFY BY NUMBER)

2. NUMBER AND TYPE OF ORANGE AIRCRAFT DESTROYED

REDEFINE THIS OUTCOME MEASURE TO EXPRESS THE ASPECT OF THE MISSION THAT IS ESSENTIAL TO MISSION SUCCESS.

NUMBER OF ORANGE SORTIES AGAINST GREY PREVENTED

The revised list of objectives and outcome measures is again summarized and tested.

A5: YOUR ANSWERS INDICATE THE FOLLOWING HIERARCHY OF OBJECTIVES

SUPERIOR'S OBJECTIVES:

1. SUPPORT GREY IN ITS EFFORTS TO DEFEAT THE REBEL GREYHAWKS AND TO RESIST AN INVASION BY ORANGE

TASK FORCE OBJECTIVES:

1. NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND

OUTCOME MEASURES:

1. NUMBER AND TYPE OF GREY UNITS DESTROYED
2. NUMBER OF ORANGE SORTIES AGAINST GREY PREVENTED
3. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED
4. PROBABILITY OF BLUE/RED WAR

IF YOU ACHIEVED DESIRED VALUES FOR EACH OF THESE OUTCOME MEASURES, IS THERE ANY WAY THE MISSION OUTCOME COULD BE UNDESIRABLE?

NO

IS THERE ANY WAY THE MISSION OUTCOME COULD BE DESIRABLE WITHOUT ACHIEVING THESE VALUES OF THE OUTCOME MEASURE?

NO

Although the outcome measures now appear to be both necessary and complete, the number of identified outcome measures (four) is fairly large, and some may be redundant or of little importance. If more than a total of 3 outcome measures are listed, the following questions are asked:

A5.1: CONSIDER EACH OUTCOME MEASURE IN TURN. IDENTIFY BY NUMBER ANY MEASURES THAT DO NOT HAVE A STRONG IMPACT ON THE DECISION.

1. NUMBER AND TYPE OF GREY UNITS DESTROYED
2. NUMBER OF ORANGE SORTIES AGAINST GREY PREVENTED
3. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED
4. PROBABILITY OF BLUE/RED WAR

The user responds with a blank and a carriage return, indicating that each outcome measure has a strong bearing on his decision.

RETAINED OUTCOME MEASURES:

1. NUMBER AND TYPE OF GREY UNITS DESTROYED
2. NUMBER OF ORANGE SORTIES AGAINST GREY PREVENTED
3. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED
4. PROBABILITY OF BLUE/RED WAR

ARE ANY OF THESE MEASURES REDUNDANT? TWO OUTCOME MEASURES ARE REDUNDANT IF KNOWING THE VALUE OF ONE ESSENTIALLY TELLS YOU THE VALUE OF THE OTHER.

YES

WHICH OUTCOME MEASURES ARE REDUNDANT? (IDENTIFY BY NUMBER)

1. NUMBER AND TYPE OF GREY UNITS DESTROYED
2. NUMBER OF ORANGE SORTIES AGAINST GREY PREVENTED

The user reasoned here that if Orange sorties against Grey are prevented, then Grey losses will, presumably, be low. The only exception might be Grey losses caused by internal fighting between Grey government forces and the rebel Greyhawks. Such losses are outside the scope of the commander's current responsibility. Therefore, the two outcome measures can be combined.

THESE OUTCOME MEASURES WILL BE COMBINED. WHAT DO YOU WISH TO CALL THE RESULT?

NUMBER OF POTENTIAL ORANGE SORTIES

The objectives and outcome identification function is concluded with a display of the final objectives hierarchy and a last verification of the completeness and necessity of each outcome measure.

A5: YOUR ANSWERS INDICATE THE FOLLOWING HIERARCHY OF OBJECTIVES

SUPERIOR'S OBJECTIVES:

1. SUPPORT GREY IN ITS EFFORTS TO DEFEAT THE REBEL GREYHAWKS AND TO RESIST AN INVASION BY ORANGE.

TASK FORCE OBJECTIVES:

1. NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND

OUTCOME MEASURES:

1. NUMBER OF POTENTIAL ORANGE SORTIES
2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED
3. PROBABILITY OF BLUE/RED WAR

IF YOU ACHIEVED DESIRED VALUES FOR EACH OF THESE OUTCOME MEASURES, IS THERE ANY WAY THE MISSION OUTCOME COULD BE UNDESIRABLE?

NO

IS THERE ANY WAY THE MISSION OUTCOME COULD BE DESIRABLE WITHOUT ACHIEVING THESE VALUES OF THE OUTCOME MEASURES?

NO

3.1.2 Alternative Generation

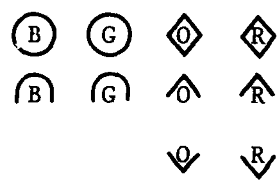
The second function in the preliminary structuring process is elicitation of decision alternatives. Alternative generation in the preliminary structuring process uses two techniques to encourage the generation of a complete list of alternatives. The first is the formalization of a "devil's advocate" role for challenging and thereby expanding each currently identified alternative. This is discussed below in the description of the alternative evaluation function. The second technique is to supply the commander with a list of generic alternatives. The list of generic alternatives used in the current implementation was derived from a study of historical decision situations compiled by CACI, Inc. [24]. By considering each generic decision type in the list, the commander can decrease the likelihood that an effective alternative has been overlooked.

Alternative generation and the subsequent function, alternative evaluation are accomplished with the aid of a simulation board (described in Subsection 1.3.1). Figures 20 through 35 illustrate the configuration and movement of game pieces for the sample application at various stages of the alternative generation and evaluation functions. A key that defines display symbols appears in Table 2.

Table 2

KEY TO SYMBOLS USED IN DISPLAYS

Blue, Grey, Orange, Red ships	
Blue, Grey, Orange, Red aircraft	
Orange, Red submarines	



With the current manual implementation of the board, simulating movement and combat engagement is fairly time-consuming. The computer basically serves as an automated instruction manual and workbook, with the user going "off-line" to perform each instruction on the board.

A fully automated simulation board would be much faster and could be fully integrated into the structuring aid.

B1: POSITION PLAYING PIECES ON THE SIMULATION BOARD IN ACCORDANCE WITH ASSUMED POSITIONS OF RELEVANT FRIENDLY AND ENEMY FORCES AT THE TIME AT WHICH AN ACTION IS CONTEMPLATED.

According to the ONRODA scenario, the commander has been ordered not to attack Orange forces unless Orange first attacks Grey and/or the task force. In this sample application, the commander believes an Orange attack is imminent. Therefore, his plan is developed under the assumption that Orange will launch an air strike against Grey at dawn.

To develop a reasonable assumption for the nature and results of an Orange attack, the user begins by tracing out on the simulation board what would appear to be an effective Orange attack strategy. In this application, Orange is assumed not to attack Blue directly, but rather to launch a massive attack directed at destroying Grey Port and the Grey defending units. Figure 20 shows the current force locations as they appear on the simulation board, and the arrows from Orange units indicate the presumed Orange attack strategy. Arrows from Red units give the anticipated locations of these units, based on their current trajectories.

To aid in the evaluation of alternative Blue actions, the simulation board may be used to estimate the initial combat results of the Orange attack. As explained in Appendix A, combat losses are calculated incrementally, based on offensive, defensive, and electronic counter measure capabilities of opposing units. Loss of a unit can occur either as a direct result of combat (from probability of kill factors or inability to

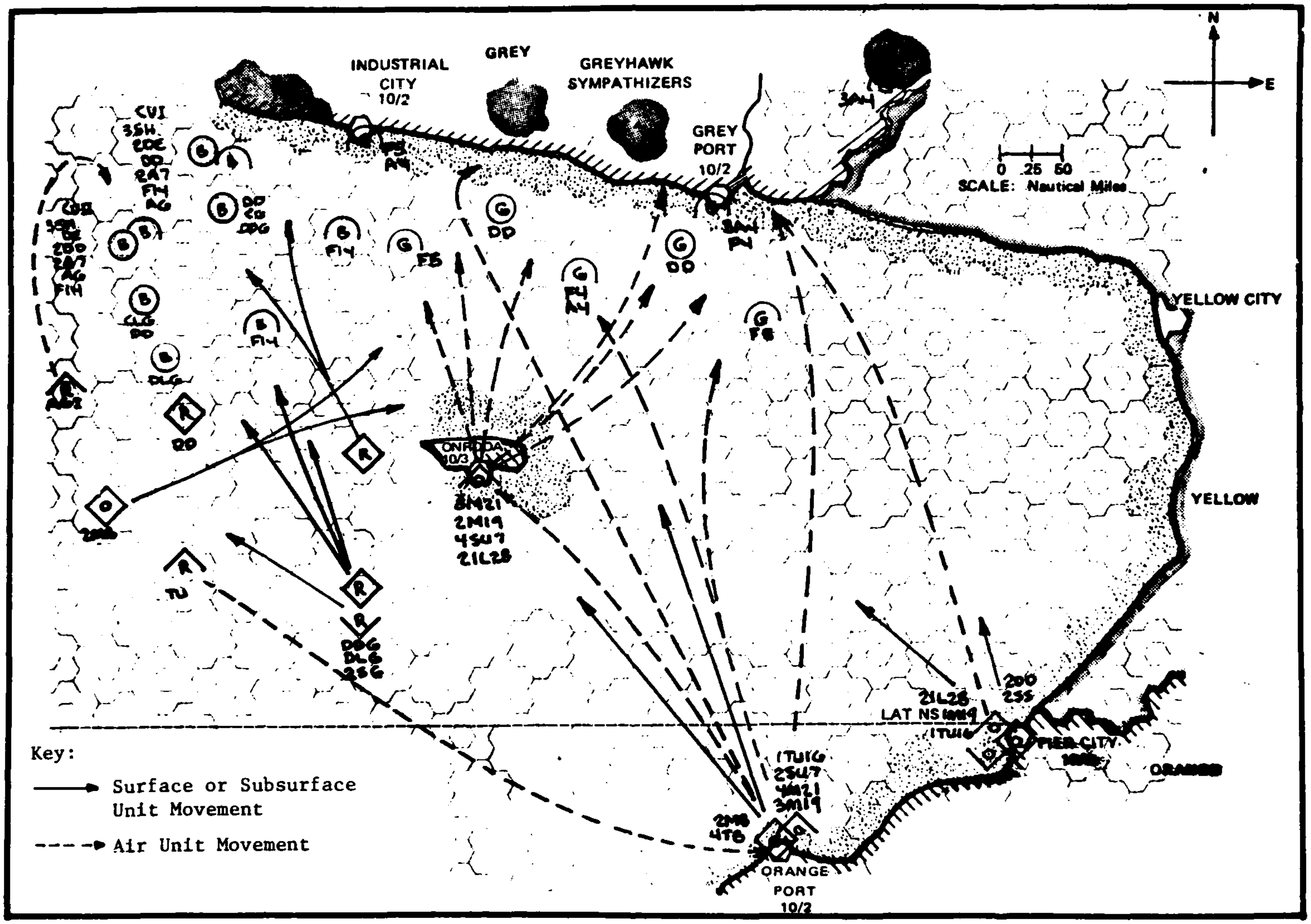


FIGURE 20 SIMULATION BOARD SHOWING CURRENT FORCE LOCATIONS AND ANTICIPATED ORANGE ATTACK ON GREY

retreat) or, in the case of aircraft, as a result of insufficient fuel to permit a safe return to a friendly carrier or land airbase. In this example, applying the logic for estimating initial combat results indicates heavy losses for both sides. Figure 21 shows the force units lost and the positions of active units as they are estimated to exist at the time at which Blue will initiate its action.

B2: PREPARE A LIST OF TENTATIVE OWN COURSES OF ACTION WHICH, IF SUCCESSFUL, WILL ACCOMPLISH THE MISSION.

1. *AIR STRIKE ONRODA*
2. *AIR BLOCKADE BETWEEN GREY AND ONRODA*
3. *DESTROY ONRODA AIRFIELD WITH NAVAL GUNFIRE*
4.

To see a template of sample alternatives, the user types *HELP*. After viewing the sample alternatives, the user is given the opportunity to expand his list:

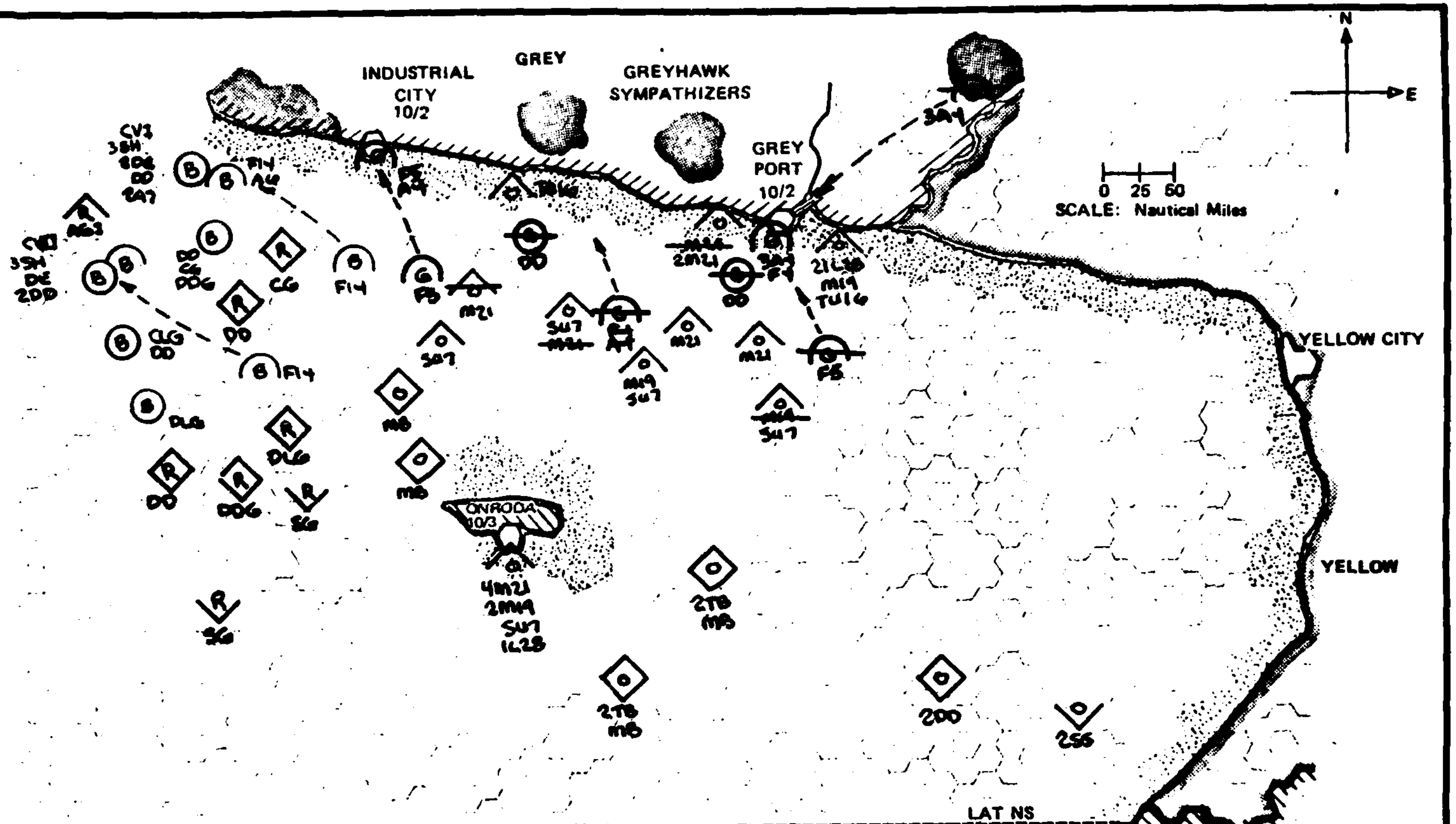
4. *HELP*

B2.1: EXAMPLES OF OWN COURSES OF ACTION INCLUDE:

1. THREATEN TO OR ACTUALLY WITHDRAW SUPPORT
2. REPOSITION FORCES
3. IMPROVE FORCE READINESS
4. CONDUCT MILITARY MANEUVERS OR TRAINING EXERCISES
5. SHOW MILITARY FORCE
6. PROVIDE PERSONNEL OR SUPPLIES
7. BLOCKADE OR MILITARY QUARANTINE
8. COMMIT SEA FORCES TO COMBAT
9. COMMIT AIR FORCES TO COMBAT
10. COMMIT GROUND FORCES TO COMBAT

DO YOU WISH TO ADD ANY OF THESE OR OTHER ALTERNATIVES TO YOUR LIST OF TENTATIVE ACTIONS? IF SO, WHAT ARE THE ADDITIONAL ALTERNATIVES?

1. *AMPHIBIOUS LANDING*
2.



Key:

- Unit Destroyed in Combat
- Air Unit Intercepted and Destroyed when Returning to Base
- Air Unit Successfully Returning to Base for Refueling

FIGURE 21 FORCE LOCATIONS AND LOSSES UNDER SIMULATED ORANGE ATTACK ON GREY

The output of the alternative generation function is a list of feasible alternatives for accomplishing the mission.

B3: ALTERNATIVES UNDER CONSIDERATION

1. AIR STRIKE ONRODA
2. AIR BLOCKADE BETWEEN GREY AND ONRODA
3. DESTROY ONRODA AIRFIELD WITH NAVAL GUNFIRE
4. AMPHIBIOUS LANDING

3.1.3 Alternative Evaluation

The output of the alternative evaluation function is an estimate of the likely outcomes and risks associated with each alternative course of action. Scenario generation is used as the basis for the evaluation. Because of their training and experience, TFCs tend to think in terms of events and reactions to events. Thus, scenarios provide a familiar, concise, and consistent framework for organizing the commander's thoughts.

Steps in the alternative evaluation function are designed to encourage the TFC and the staff to generate scenarios that produce likely outcomes of a given course of action as well as scenarios that make the action look very bad. Generating a scenario that makes an action look very bad accomplishes two things. First, it counteracts a general error or bias in decision-making sometimes referred to as "mindguards." A mindguard is an observed tendency for a decision-maker to limit or distort his world view so as to produce a less threatening perception of a difficult situation. The result of mindguards is usually a failure to consider adequately the risks or negative aspects of a preferred course of action. Formalizing a devil's advocate evaluation of each alternative causes a deliberate attempt to be made to counteract the tendency to create mindguards.

A second value to explicitly considering unfavorable scenarios is encouragement of alternative generation. Consideration of possible risks inherent in a course of action challenges the commander and his staff to devise modifications or new alternatives that achieve the same benefits without the risks. An earlier phase of the SRI research [14] indicated that challenging a decision-maker by pointing out specific disadvantages or risks associated with a preferred action is an effective way to encourage the creation of new alternatives. For this reason, as will be seen below, the alternative generation function is repeated after each execution of the alternative evaluation function.

Analysis of alternatives begins with an evaluation of the course of action that initially appears most promising to the user.

C1: GIVEN YOUR PRESENT STATE OF KNOWLEDGE, WHICH COURSE OF ACTION APPEARS TO HAVE THE BEST CHANCE FOR SUCCESS? (IDENTIFY BY NUMBER)

1. AIR STRIKE ONRODA

Beginning with the initially preferred alternative ensures that the results of the structuring process will be of value in decision-making even if the structuring process should be interrupted before completion.

C2: ASSUME THE ALTERNATIVE "AIR STRIKE ONRODA." USING THE SIMULATION BOARD:

1. TRACE OUT PLANNED OWN FORCE MOVEMENT AND SIMULATE ENGAGEMENT LOSSES.

Planned own force movement for the air strike as initially traced out by the commander (Figure 22) is as follows:

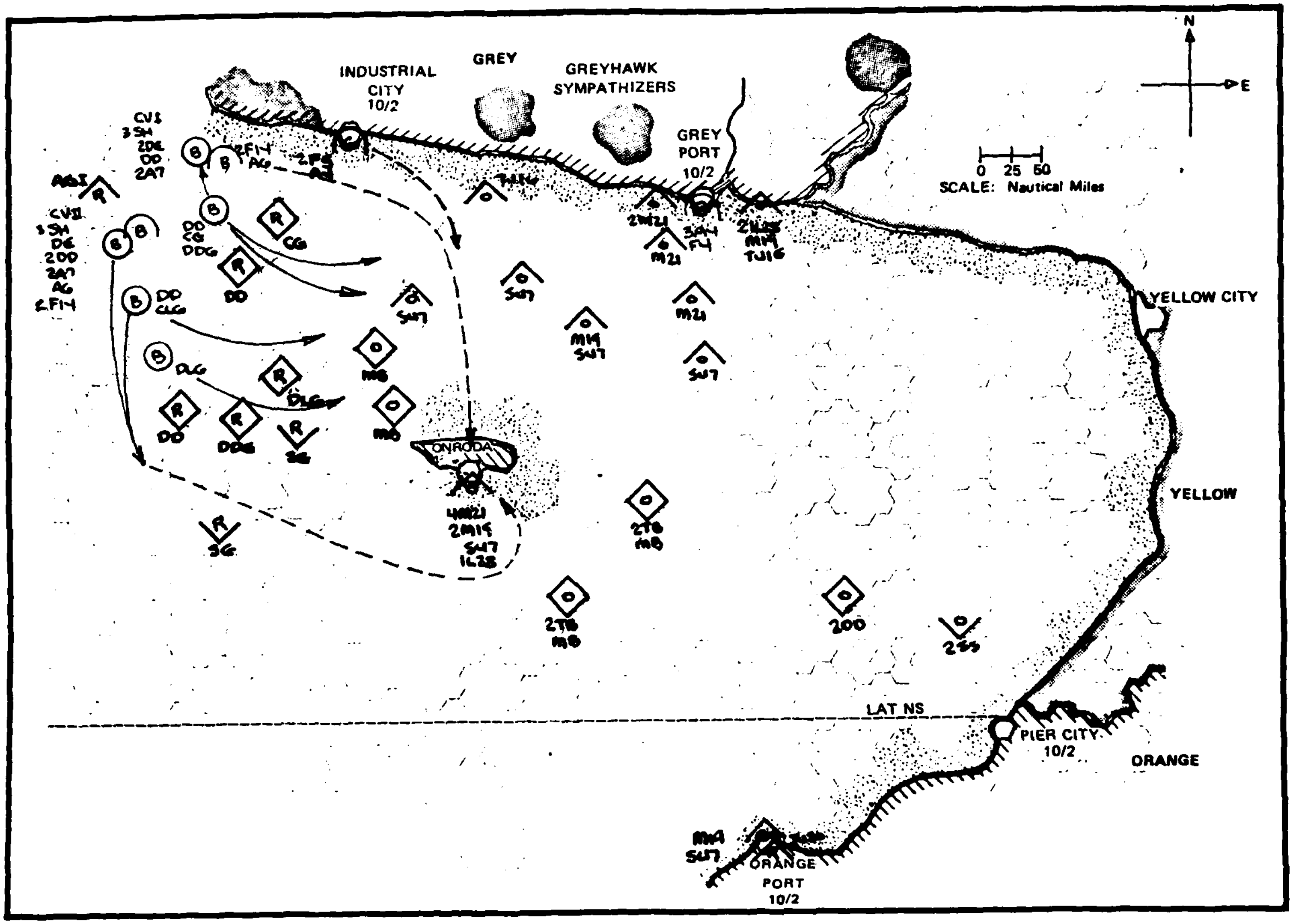


FIGURE 22 COMMANDER'S FIRST AIR STRIKE PLAN

- CVI surface defenses consolidated
  - DD returned to CVI
  - DDG and CG set up surface defense midway between ONRODA and Industrial City
- CVII and support ships moved to position 250nmi west of ONRODA
  - DD returned to CVII
  - CLG to engage Orange surface defense (1xMB) on west side of ONRODA
  - DLG to engage Orange surface defense (1xMB) on northwest side of ONRODA
- Air strike
  - CVI sends air strike (1xF14, 2xA7) to attack ONRODA from southeast and to intercept any Orange reinforcements arriving from Orange Port and Pier City
  - CVII sends air strike (1xF14, 1xA6, 1xA7) to attack ONRODA from north and to intercept Orange units returning from attack on Grey Port.

Because the playing pieces used with the simulation board are labeled according to corresponding unit capabilities, intended movement patterns can be checked for feasibility in view of time/distance factors, transit speeds, movement constraints, and offensive and defensive strength capabilities. An automated version of the simulation board would actually show the pieces moving to highlight forced deviations from the intended movement pattern.

Simulation board logic can be used to estimate combat losses incurred during the later period of the Orange attack on Grey Port and losses resulting during the initial phase of the Blue air strike on ONRODA. Figure 23 shows the locations of opposing forces resulting from the air

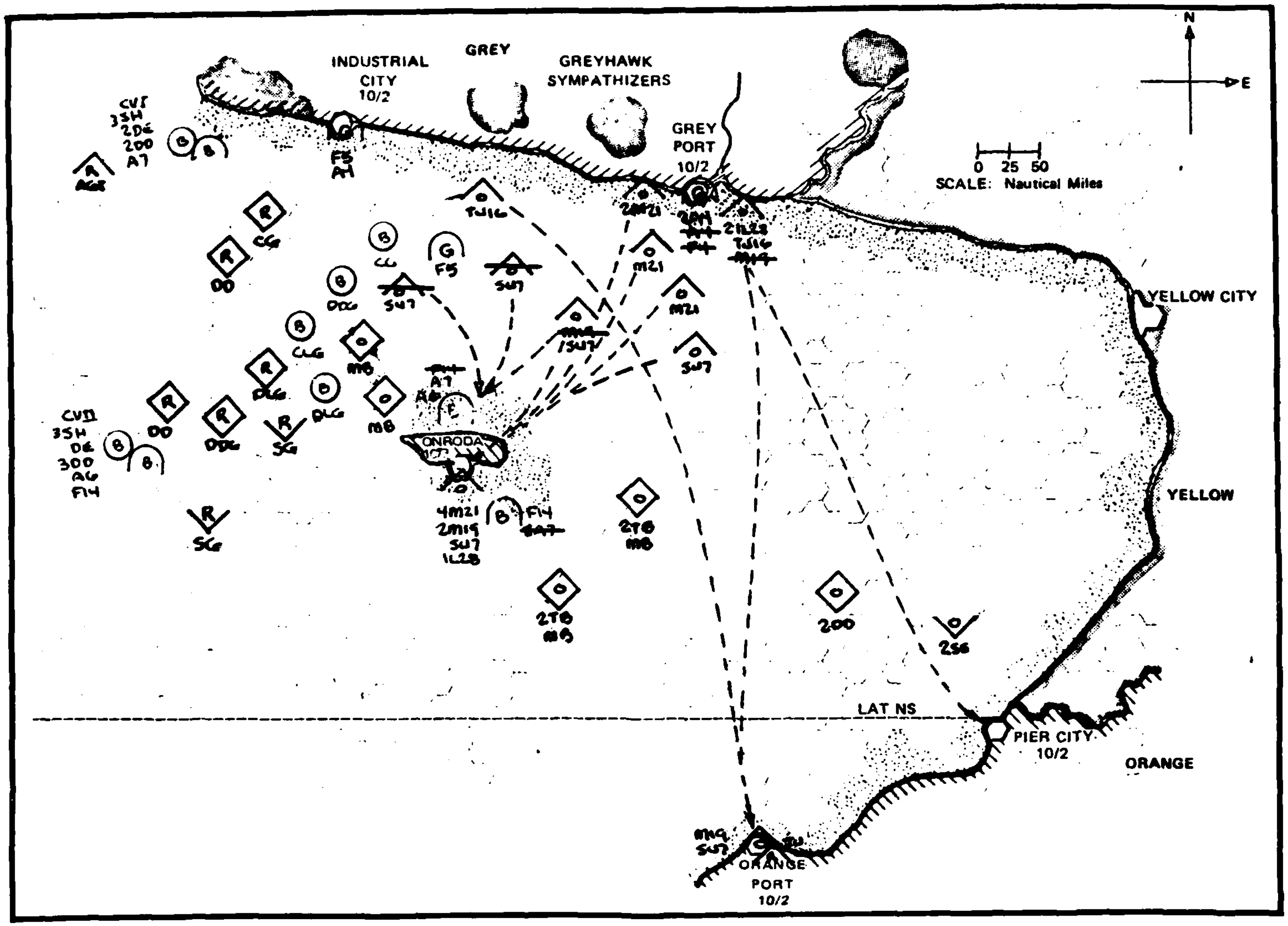


FIGURE 23 FORCE LOCATIONS AND INITIAL LOSSES ESTIMATED THROUGH SIMULATION OF FIRST AIR STRIKE PLAN

strike attack strategy, the losses estimated through combat simulation, and the return routes taken by surviving Orange aircraft.

2. TRACE OUT ANTICIPATED ENEMY RESPONSE AND SIMULATE ENGAGEMENT LOSSES.

Anticipated Orange reaction to the Blue air strike is shown in Figure 24. Basic assumptions are:

- Neither Orange nor Red attacks the task force directly
- Orange attempts to bring air reinforcements (1xMIG19), (1xSU7) to ONRODA from Orange Port
- Surface units (2xTB, MB) join retreating units (MB) to provide defense line north of ONRODA
- Orange launches second air strike against Grey Port, and stations air blockade between ONRODA and CVII designed to intercept and prevent return of Blue aircraft to CVII.

Movement simulation indicates that Blue units attacking ONRODA from the southeast are not successful in blocking air reinforcements from Orange Port. Combat simulation shows heavy losses for both Blue and Orange at ONRODA. Although remaining Blue attacking units inflict heavy damage to Orange aircraft protecting ONRODA, the Blue aircraft are intercepted and destroyed during their attempted return to the carriers. These and other estimated losses indicated by simulation are shown in Figure 25.

In summary, simulation of the air strike alternative as initially specified by the commander under anticipated enemy response suggests heavy losses for Blue, Grey, and Orange. Total losses are summarized in Table 3.

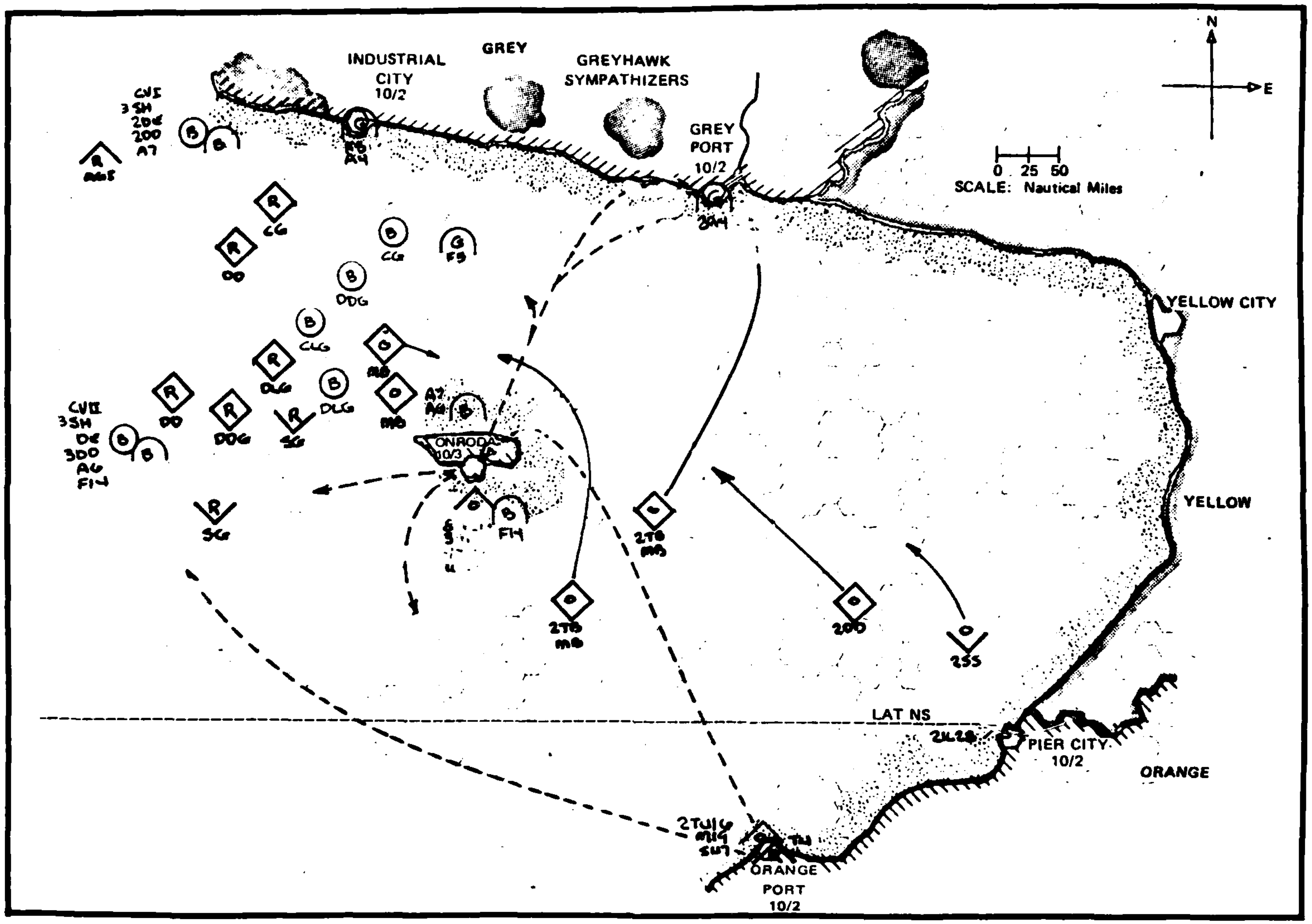


FIGURE 24 ANTICIPATED ORANGE REACTION TO FIRST AIR STRIKE PLAN SHOWING CONTINUED ORANGE ATTACK ON GREY AND BLOCKADE INTENDED TO PREVENT BLUE PLANES FROM RETURNING TO CVII

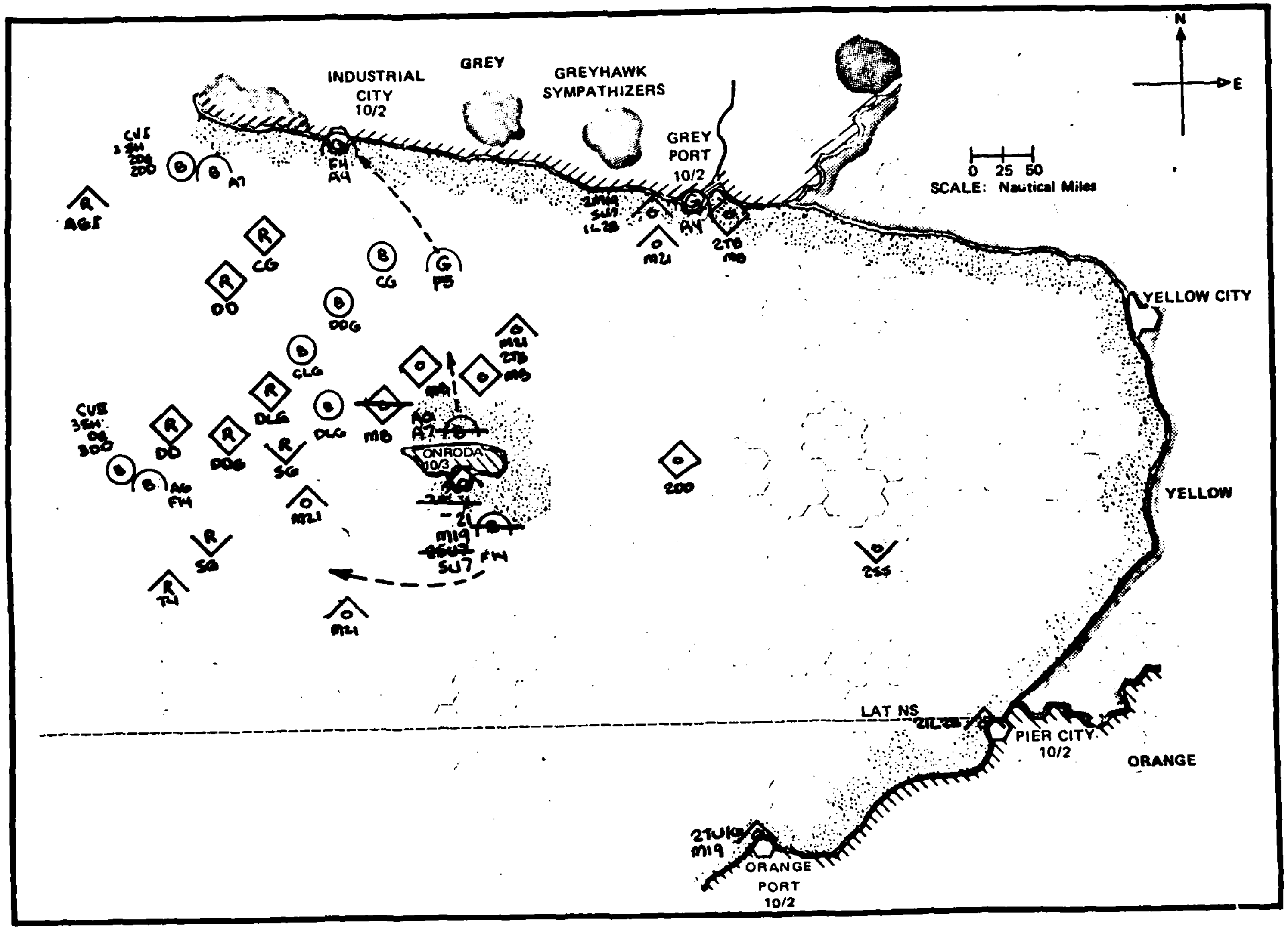


FIGURE 25 FORCE LOCATIONS AND SUBSEQUENT LOSSES UNDER ANTICIPATED ORANGE RESPONSE TO FIRST AIR STRIKE PLAN

Table 3

ESTIMATED LOSSES
INITIAL AIR STRIKE PLAN--ANTICIPATED ENEMY RESPONSE

	Aircraft	Ships
Blue	2xF14, 3xA7, 1xA6	
Grey	2xF4, 1xF5, 5xA4	2xDD
Orange	7xMIG21, 3xMIG19, 4xSU7	1xMB

Although Orange's air forces are largely destroyed, Orange has succeeded in eliminating most of Grey's air defenses and appears on the verge of destroying Grey Port.

3. REVISE YOUR ACTION PLAN AS NECESSARY IN LIGHT OF SIMULATION RESULTS.

In this sample application, the user elected to modify his attack strategy in light of simulation results before proceeding further. As indicated above, simulation has shown that attacking ONRODA from the southeast will not be effective in preventing reinforcements from reaching ONRODA and that the extra fuel requirements and tactical difficulties make the attack planes more vulnerable.

Figure 26 shows the commander's revised air strike plan. The intended movement pattern is identical to the initial strategy except:

- The attack squadron (A7) from CVI is directed at the missile boats (2xMB) rather than at ONRODA Island
- The attack force from CVII (F14, 2xA6) attacks ONRODA Island from the west rather than from the southeast.

Simulation of combat gives virtually identical initial losses to those estimated previously. The anticipated Orange counterstrategy, shown in

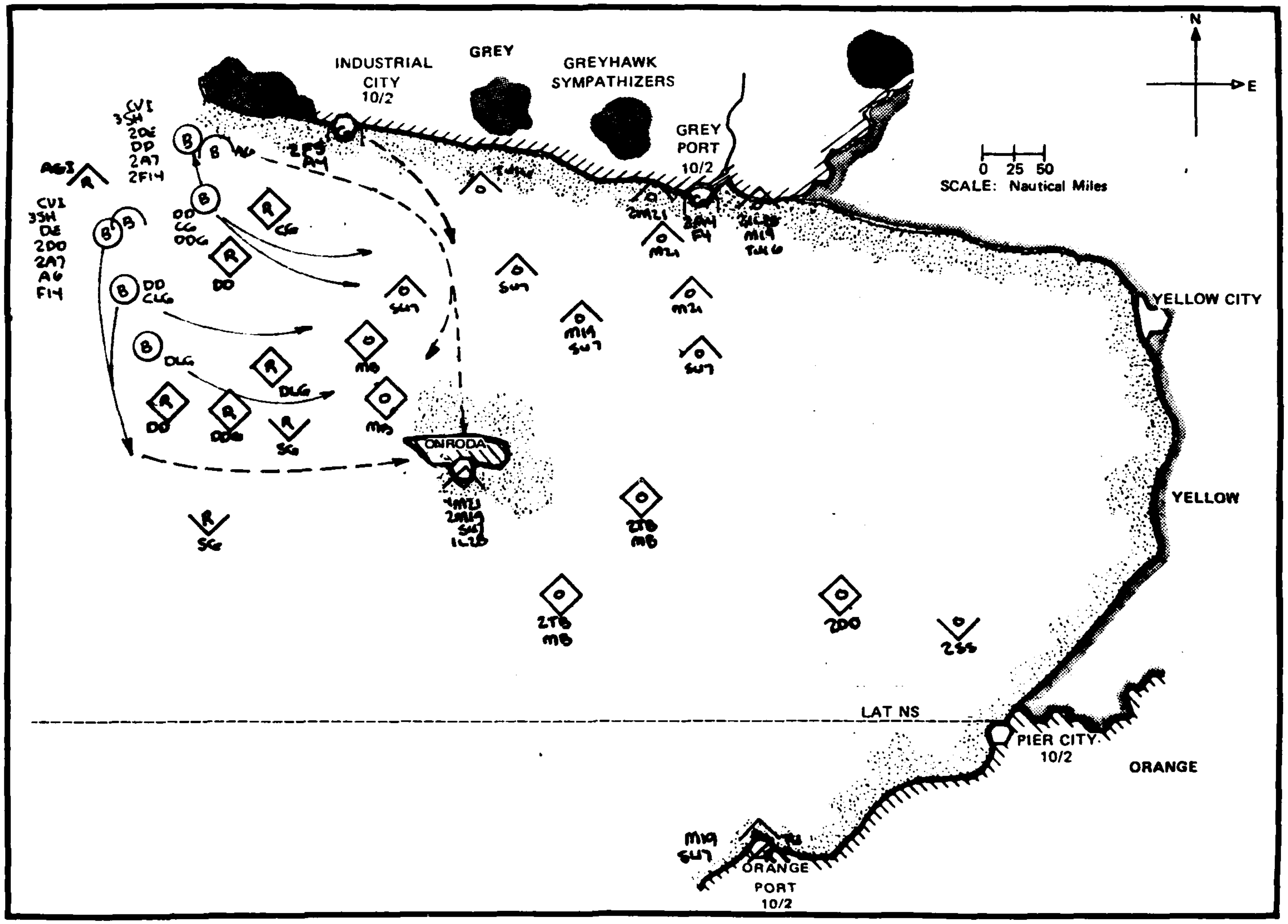


FIGURE 26 REVISED AIR STRIKE PLAN

Figure 27, is also very similar to the previous case. Combat simulation now shows, however, that both Orange missile boats are destroyed. This provides a safe route that permits the remaining Blue attack planes to return to their respective carriers (Figure 28). Total losses under the revised plan are shown in Table 4. Comparing this with estimated losses under the first strategy (Table 3) shows a significant improvement.

Table 4

ESTIMATED LOSSES
REVISED AIR STRIKE PLAN--ANTICIPATED ENEMY RESPONSE

	Aircraft	Ships
Blue	1xF14, 2xA7	
Grey	2xF4, 1xF5, 5xA4	2xDD
Orange	7xMIG21, 5xSU7, 2xMIG19	2xMB

The next step in the alternative evaluation function is to evaluate the strategy, in light of simulation results, according to each of the outcome measures. In making this evaluation, it is important for the user to bear in mind that the primary function of the simulation board is to facilitate translating alternative strategies into specific actions that are consistent with the constraints of available resources and environment. It is not necessarily a device for forecasting outcomes. If the commander believes the simulation board is a good representation of his real-world situation, he may believe the estimates produced by the board are reasonably good predictors. It is likely however, that the commander would want to incorporate the results of simulation along with other information and judgment to produce a more comprehensive subjective assessment of the likely consequences of each tentative course of action.

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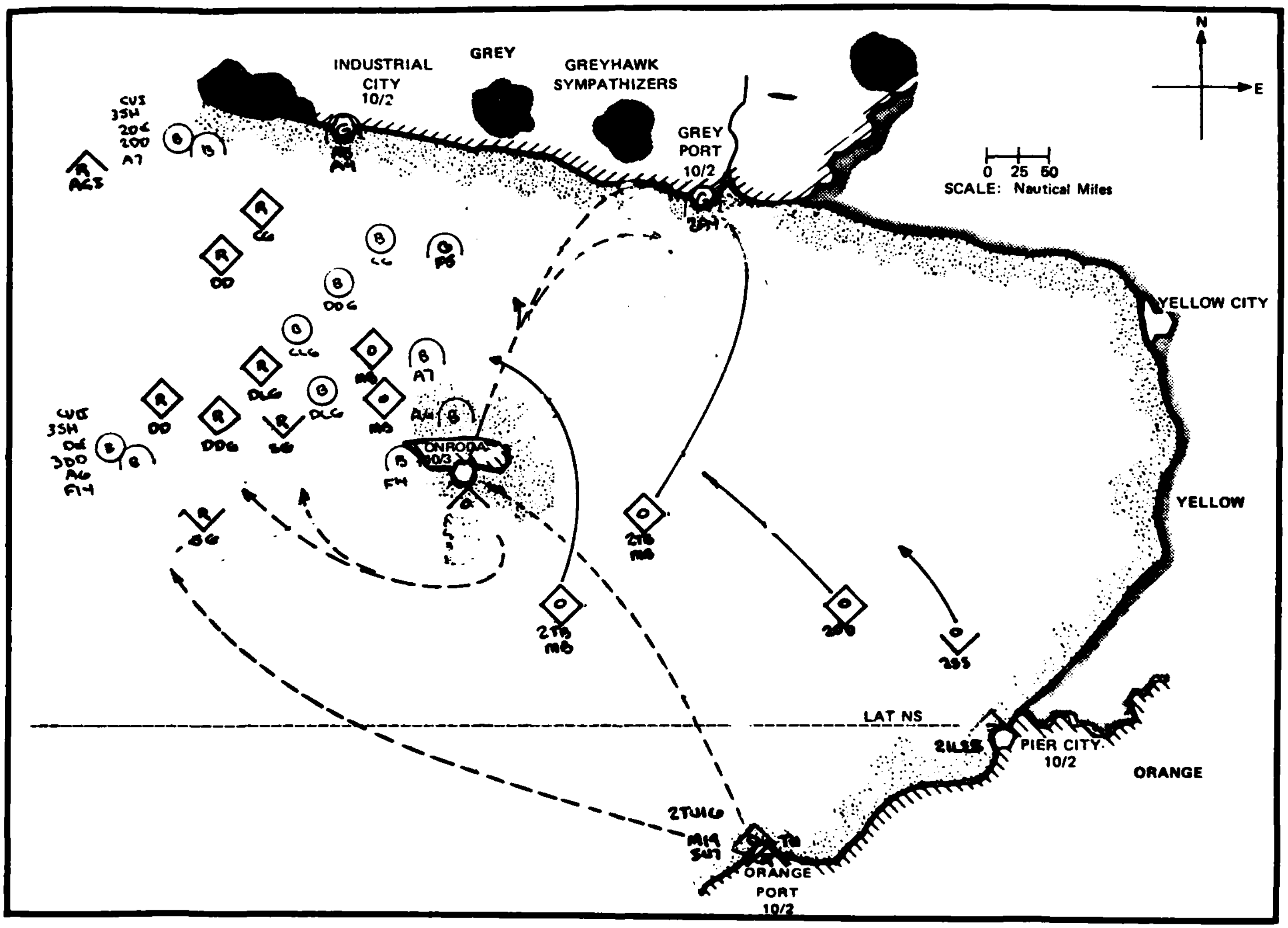


FIGURE 27 ANTICIPATED ORANGE REACTION TO REVISED AIR STRIKE PLAN

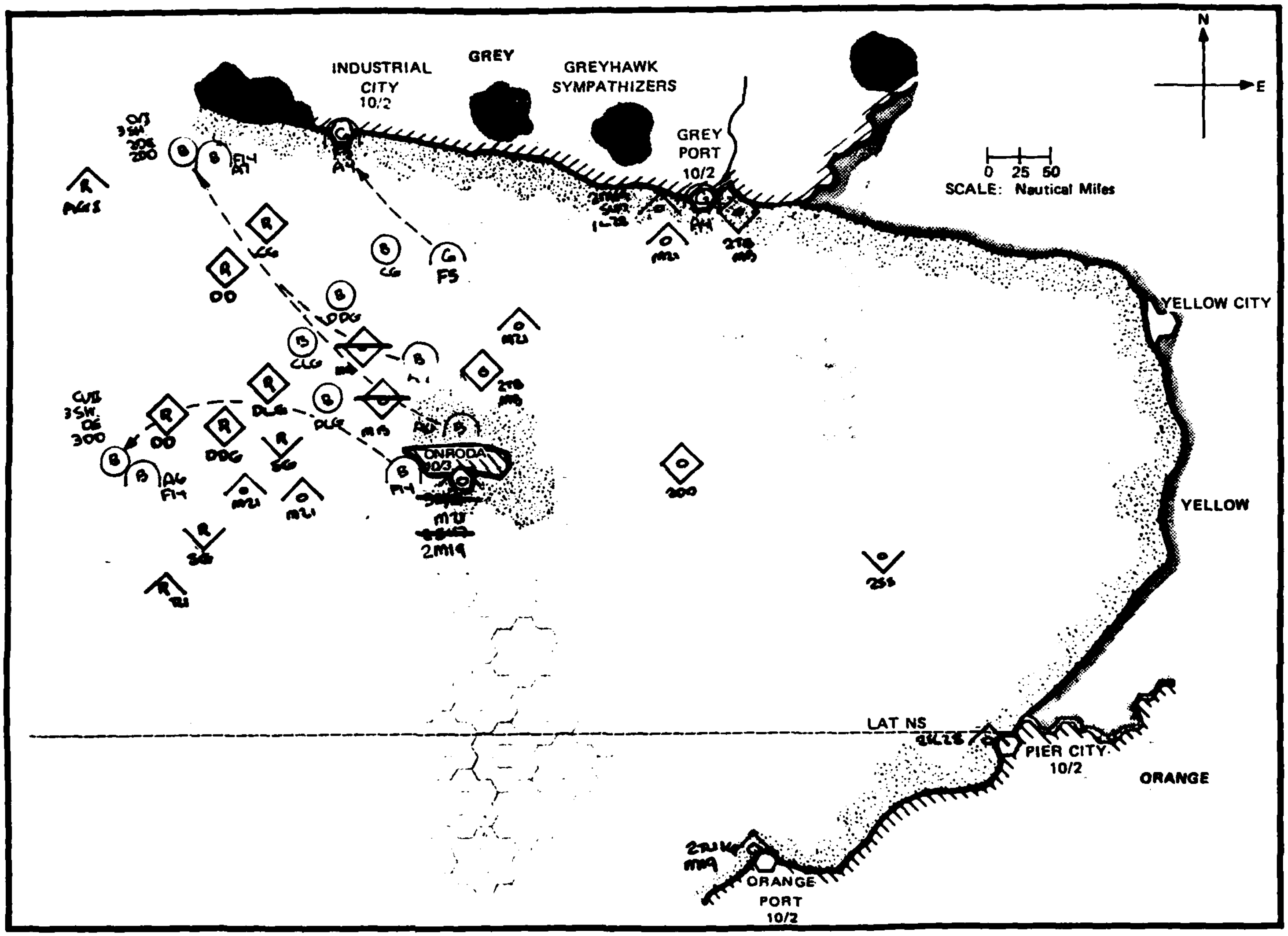


FIGURE 28 SUBSEQUENT LOSSES UNDER ANTICIPATED ORANGE REACTION TO REVISED AIR STRIKE SHOWING DESTRUCTION OF ORANGE MISSILE BOATS; SURVIVAL OF REMAINING BLUE ATTACK PLANES

C3: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "AIR STRIKE ONRODA" UNDER THE ANTICIPATED ENEMY RESPONSE

1. NUMBER OF POTENTIAL ORANGE SORTIES:

ORANGE COULD POTENTIALLY LAUNCH UP TO TWO MAJOR AIR STRIKES AGAINST GREY BEOFRE ORANGE LOSES THE MAJORITY OF ITS AIR UNITS

2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED:

UP TO 50% OF THE ATTACKING AIRCRAFT

3. PROBABILITY OF BLUE/RED WAR:

1 CHANCE IN 100

The preferred alternative has now been systematically evaluated assuming a likely event scenario. The next step is to evaluate it assuming a worst-case scenario.

C4: IDENTIFY SCENARIOS THAT MAKE THE ALTERNATIVE "AIR STRIKE ONRODA" LOOK VERY BAD. SELECT THE SCENARIO OF GREATEST CONCERN TO YOU. USING THE SIMULATION BOARD:

1. TRACE OUT ENEMY FORCE MOVEMENTS UNDER YOUR WORST-CASE SCENARIO AND ESTIMATE ENGAGEMENT LOSSES.

The commander's main concern is his vulnerability to attack. He first considers the possibility of an Orange attack on the task force.

The Orange movement anticipated by the commander in the event of an attack on the task force is shown in Figure 29. Because CVI has been positioned out of range of Orange fighters, the assumed Orange attack is against CVII and CVI's light destroyer with guided missiles (DLG) positioned closest to ONRODA. The air attack against CVI consists of all ready aircraft that Orange is capable of launching (4xMIG21, 2xMIG19, 1xSU7, 1xIL28).

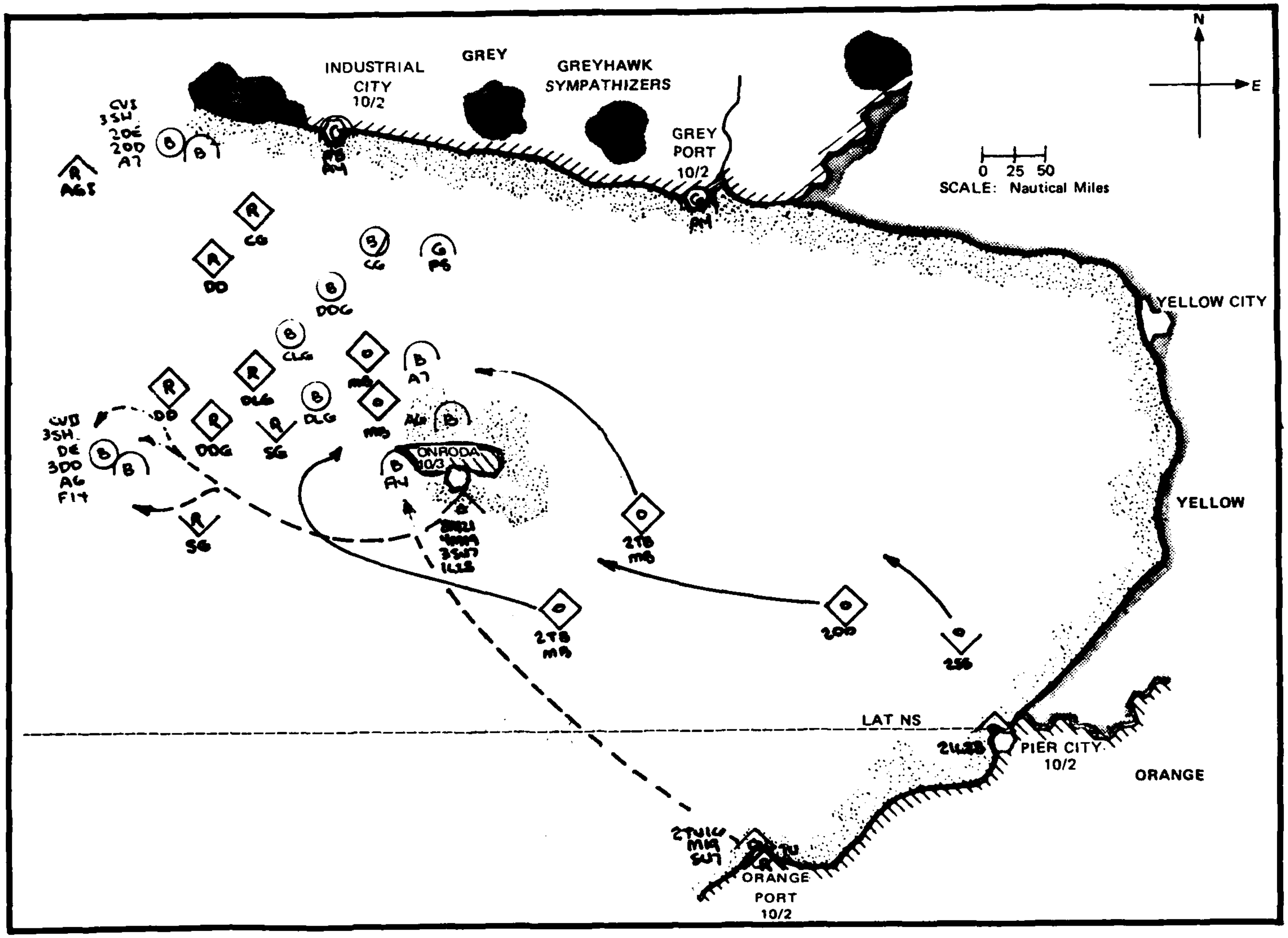


FIGURE 29 COMMANDER'S FIRST WORST-CASE SCENARIO: ORANGE ATTACK ON TASK FORCE

Simulation of combat shows that the concentration of Orange forces around ONRODA Island under an Orange counterattack results in greater losses to the Blue attack force. Contrary to the commander's initial fears, however, the simulation board does not indicate major ship damage to CVII. Total losses estimated under the Orange attack are summarized in Table 5.

Table 5

ESTIMATED LOSSES
REVISED AIR STRIKE PLAN--INITIAL WORST-CASE SCENARIO

	Aircraft	Ships
Blue	2.33xF14, 2xA7, 1xA6	.33XDE
Grey	2xF4, 1xF5, 5xA4	2xDD
Orange	10xMIG21, 5xMIG19, 6xSU7	2xMB

Low losses to CVII occur because the commander has left one squadron each of F14s and A6s to defend the carrier. These planes together with the strong antiair capability of the ships surrounding CVII form a potent defense against the Orange attacking aircraft.

In this sample application, the user elected to revise his worst-case scenario in light of the above results. Although not now so concerned about an attack solely from Orange, he is concerned about a joint attack by Orange plus Red. He therefore traces out the movement anticipated in the event of a Red attack, as shown in Figure 30. Movement assumptions are:

- Red attacks CVI with its three northernmost ships (CG, DD, and DLG)
- Red and Orange launch a coordinated attack against CVII:

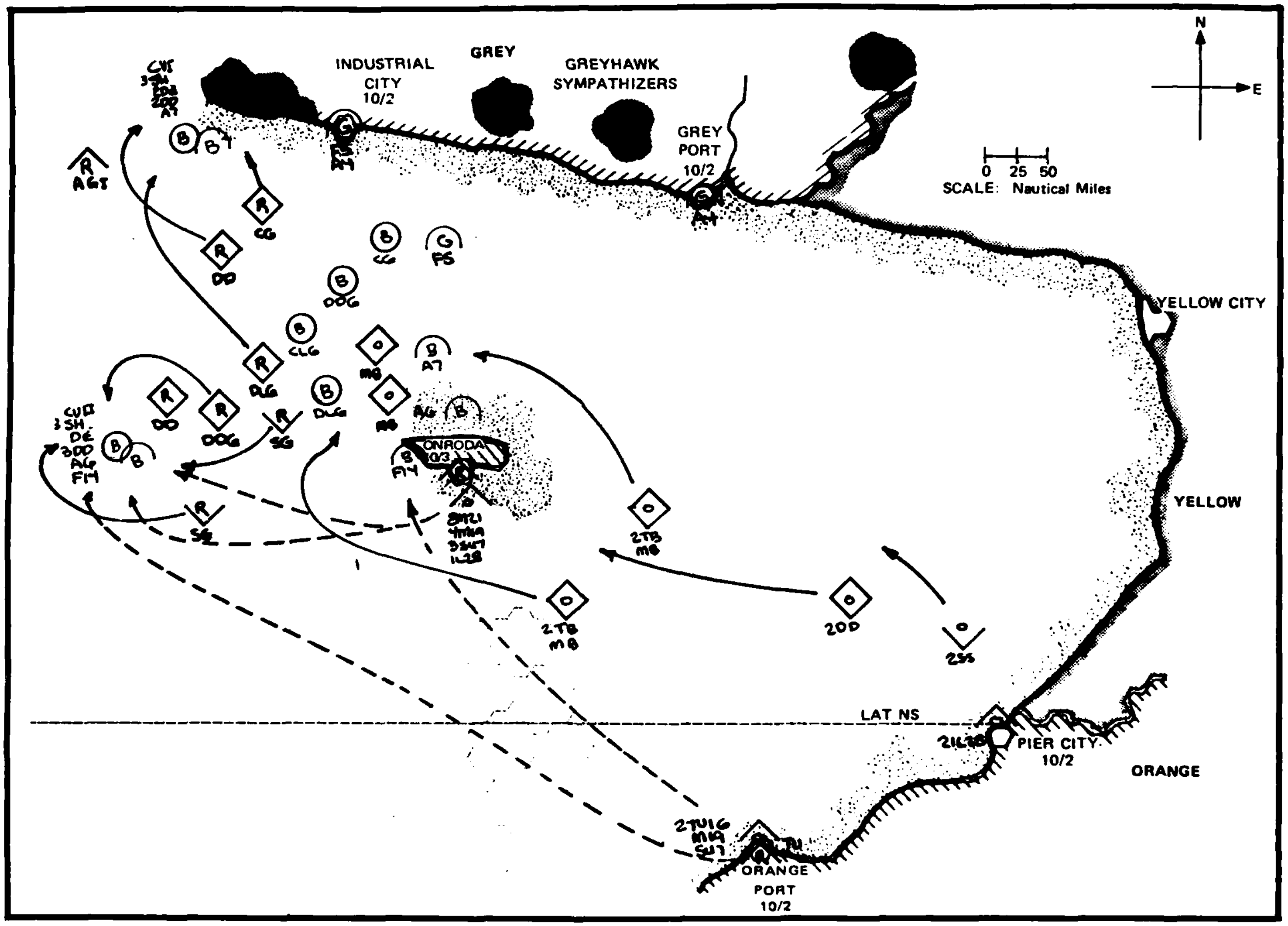


FIGURE 30 REVISED WORST-CASE SCENARIO: RED ATTACK

- Red attacks CVII with its remaining ships and submarines (2xSG, DD, DDG)

- Red sends its long-range bomber (TU20) located at Orange Port toward CVII and attacks from the southwest

- Orange launches a massive air attack (4xMIG21, 2xMIG19, 1xSU7, 1xIL28) engaging EVII from the south and east.

Positions of opposing forces and estimated losses are shown in Figure 31.

Total losses under this scenario are shown in Table 6.

Table 6

ESTIMATED LOSSES
REVISED AIR STRIKE PLAN--REVISED WORST-CASE SCENARIO

	Aircraft	Ships
Blue	2.33xF14, 3.33xA7, 1.33xA6, 1xSH	.33xDE, 2xDD, .16xCVII
Grey	2xF4, 1xF5, 5xA4	
Orange	10XMIG21, 5xMIG19, 6xSU7	

It is clear from the magnitude of estimated losses that the task force is vulnerable to a coordinated Orange/Red attack. Most of the estimated Blue ship damage is due to the submarine attack on CVII.

C5: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "AIR STRIKE ONRODA" UNDER THE WORST-CASE SCENARIO

1. NUMBER OF POTENTIAL ORANGE SORTIES:

ORANGE COULD POTENTIALLY LAUNCH ONLY TWO MAJOR AIR STRIKES AGAINST GREY BEFORE ORANGE LOSES THE MAJORITY OF ITS AIR UNITS

2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED:

SIGNIFICANT DAMAGE TO CVII PLUS LOSS OR DAMAGE OF RELATED SHIPS. LOSS OF UP TO 2/3 OF AIRCRAFT ON CVI

3. PROBABILITY OF BLUE/RED WAR:

1 CHANCE IN 10

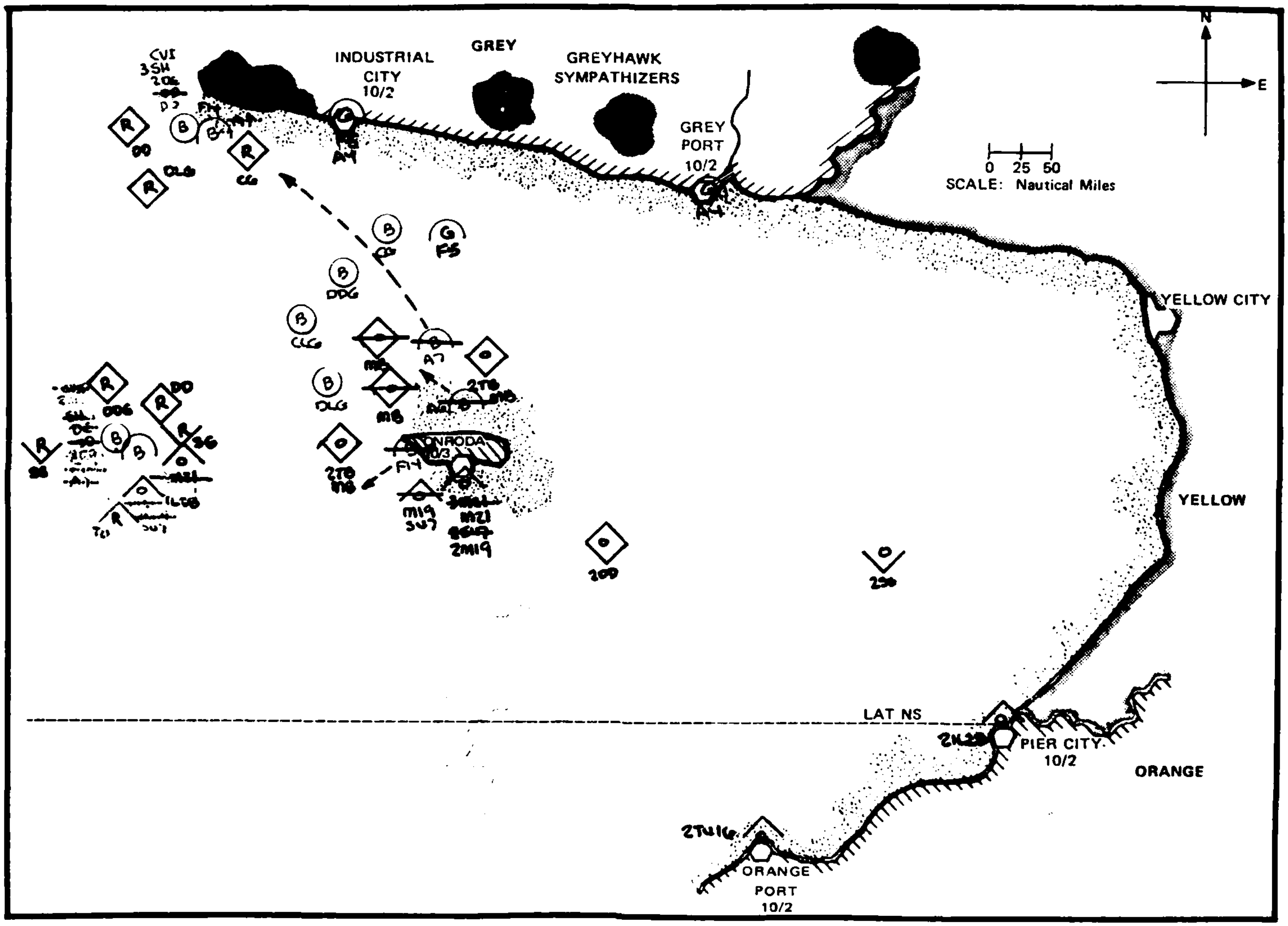


FIGURE 31 SUBSEQUENT LOSSES UNDER REVISED WORST-CASE SCENARIO

The initially preferred alternative has now been evaluated under anticipated and worst-case event scenarios, and estimated results have been summarized according to each outcome measure.

3.1.4 Critical Uncertainty Identification

The output of the critical uncertainty identification function is a list of uncertainties whose probabilities should be explicitly addressed. The approach in generating the list is to compare the most likely and worst scenarios for the alternative under consideration. The differences in the scenarios represent uncertain events that influence the relative preference for the alternatives.

D1: IF A SIGNIFICANT DIFFERENCE EXISTS BETWEEN THE TWO SCENARIOS, WHAT EVENT OR EVENTS ARE MOST RESPONSIBLE FOR THE DIFFERENCE?

1. *RED ATTACK*
2.

3.1.5 Alternative Evaluation

Having completed the evaluation of the air strike alternative, the user is now given the opportunity to conduct a similar evaluation of his other options.

C1': ARE THERE OTHER ALTERNATIVE COURSES OF ACTION THAT YOU WISH TO EXPLORE? (IDENTIFY BY NUMBER)

1. AIR STRIKE OF ONRODA FOLLOWED BY ORANGE/ONRODA BLOCKADE
2. AIR BLOCKADE BETWEEN GREY AND ONRODA
3. DESTROY ONRODA AIRFIELD WITH NAVAL GUNFIRE
4. AMPHIBIOUS LANDING
5. OTHER (SPECIFY)

2. AIR BLOCKADE BETWEEN GREY AND ONRODA

C2: ASSUME THE ALTERNATIVE "AIR BLOCKADE BETWEEN GREY AND ONRODA." USING THE SIMULATION BOARD:

1. TRACE OUT PLANNED OWN FORCE MOVEMENT AND SIMULATE ENGAGEMENT LOSSES.

2. TRACE OUT ANTICIPATED ENEMY RESPONSE AND SIMULATE ENGAGEMENT LOSSES.

3. REVISE YOUR ACTION PLAN AS NECESSARY IN LIGHT OF SIMULATION RESULTS.

Although the commander has serious doubts about the air strike alternative, he is not optimistic that a blockade will appear much better. As with the air strike, the commander assumes Orange will strike Grey Port at dawn. He does not have sufficient time to put the blockade in place before the first attack. He is also concerned about whether he has enough air power to turn back subsequent Orange attacks. Figure 32 shows the movement plan that uses the commander's limited resources:

- Surface and defensive air units relied on to block attacks against Industrial City:
  - CVI and support ships moved east to a position 50-100nmi off Industrial City
  - CVII moved southeast to a position midway between ONRODA and Industrial City
  - DDG and CG positioned between ONRODA and Grey coast. DLG engages Orange missile boat to north-west of ONRODA. DD and CLG positioned between CVI and CVII.
- Air units used are to block attacks against Grey Port:
  - Air units (1xF14, 2xA7) from CVI and air units (1xF14, 2xA7) from CVII stationed as primary and secondary defenses between ONRODA and Grey Port.

As shown in Figure 33, simulation of initial losses shows the Blue air blockade to be effective at intercepting and destroying Orange aircraft

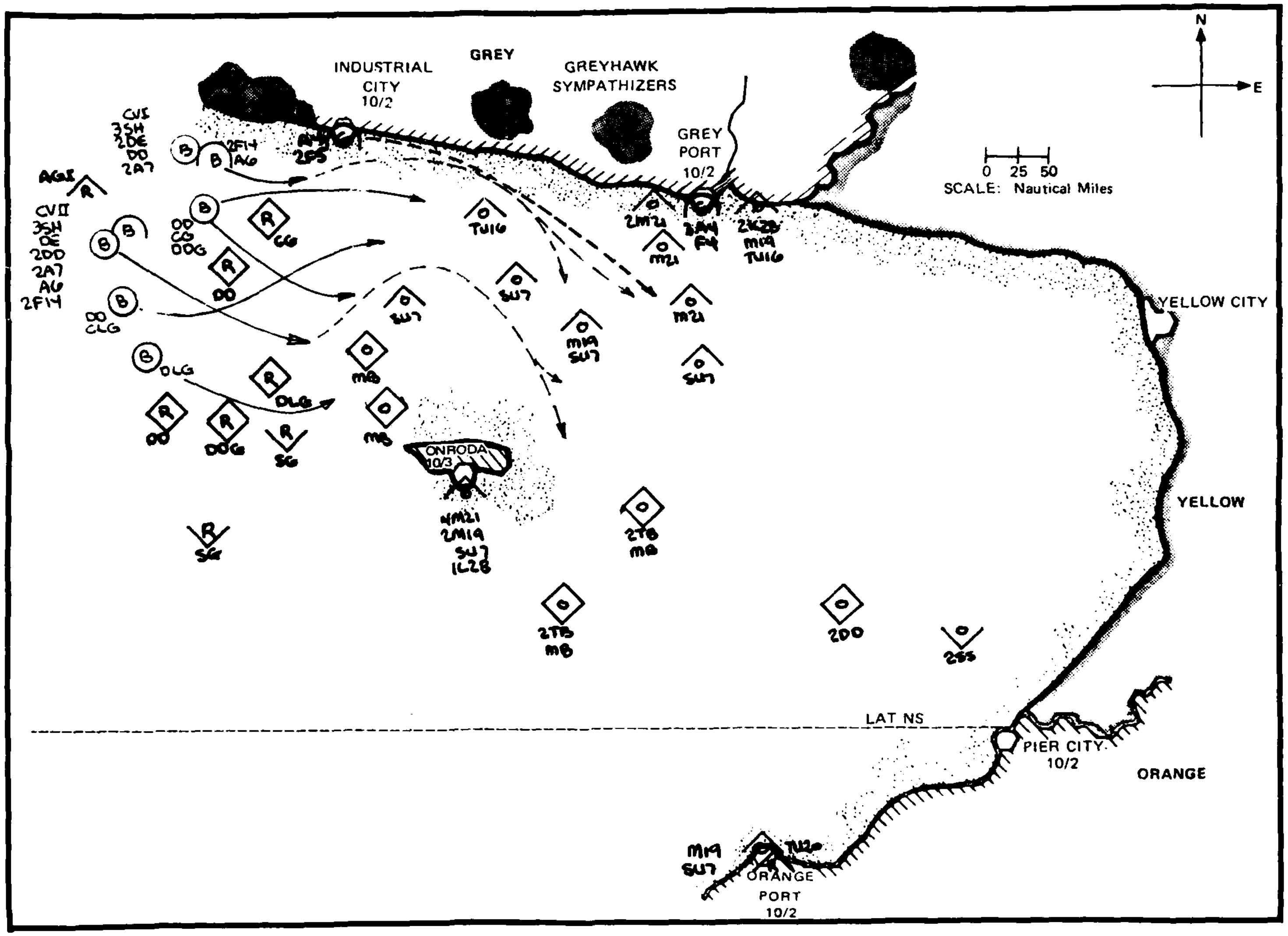


FIGURE 32 COMMANDER'S BLOCKADE PLAN

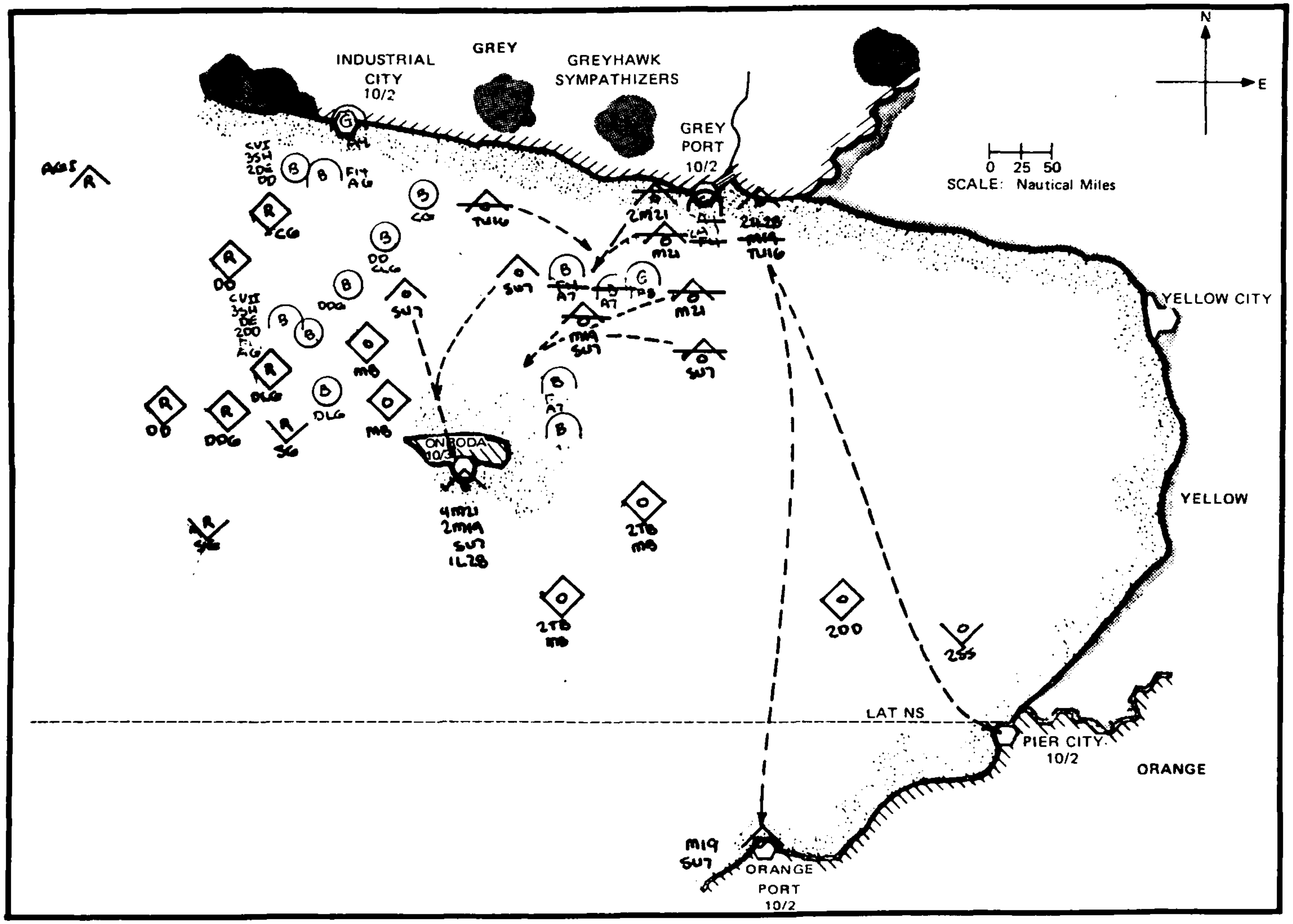


FIGURE 33 INITIAL LOSSES ESTIMATED THROUGH SIMULATION OF THE BLOCKADE

returning to ONRODA from the attack on Grey Port.

Anticipated Orange response as traced out by the commander is shown in Figure 34. Again, the commander assumes that Orange will not risk attacking the task force directly, but will attempt a second massive attack against Grey Port. Simulation logic indicates that Orange is partially successful in breaking the Blue air blockade. Two Orange fighter squadrons and bombers reach Grey Port and are joined by Orange torpedo and missile boats that join in the attack. Simulation indicates total losses shown in Table 7.

Table 7

ESTIMATED LOSSES
BLOCKADE--ANTICIPATED ENEMY RESPONSE

	Aircraft	Ships
Blue	1xF14, 1xA7	
Grey	1xF5, 2xF4, 5xA4	2xDD
Orange	9xMIG21, 4xMIG19, 3xSU7, 1xTU14	

Comparing Table 7 loss estimates from the blockade with estimates from the air strike alternative (Table 3) shows the blockade to result in fewer Blue losses, greater Orange losses, and the same losses to Grey, under the anticipated enemy response.

C3: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "AIR BLOCKADE BETWEEN GREY AND ONRODA" UNDER THE ANTICIPATED ENEMY RESPONSE

1. NUMBER OF POTENTIAL ORANGE SORTIES:

ORANGE COULD POTENTIALLY LAUNCH UP TO TWO MAJOR AIR STRIKES AGAINST GREY BEFORE ORANGE LOSES THE MAJORITY OF ITS AIR UNITS

2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED:

UP TO 30% OF THE ATTACKING AIRCRAFT

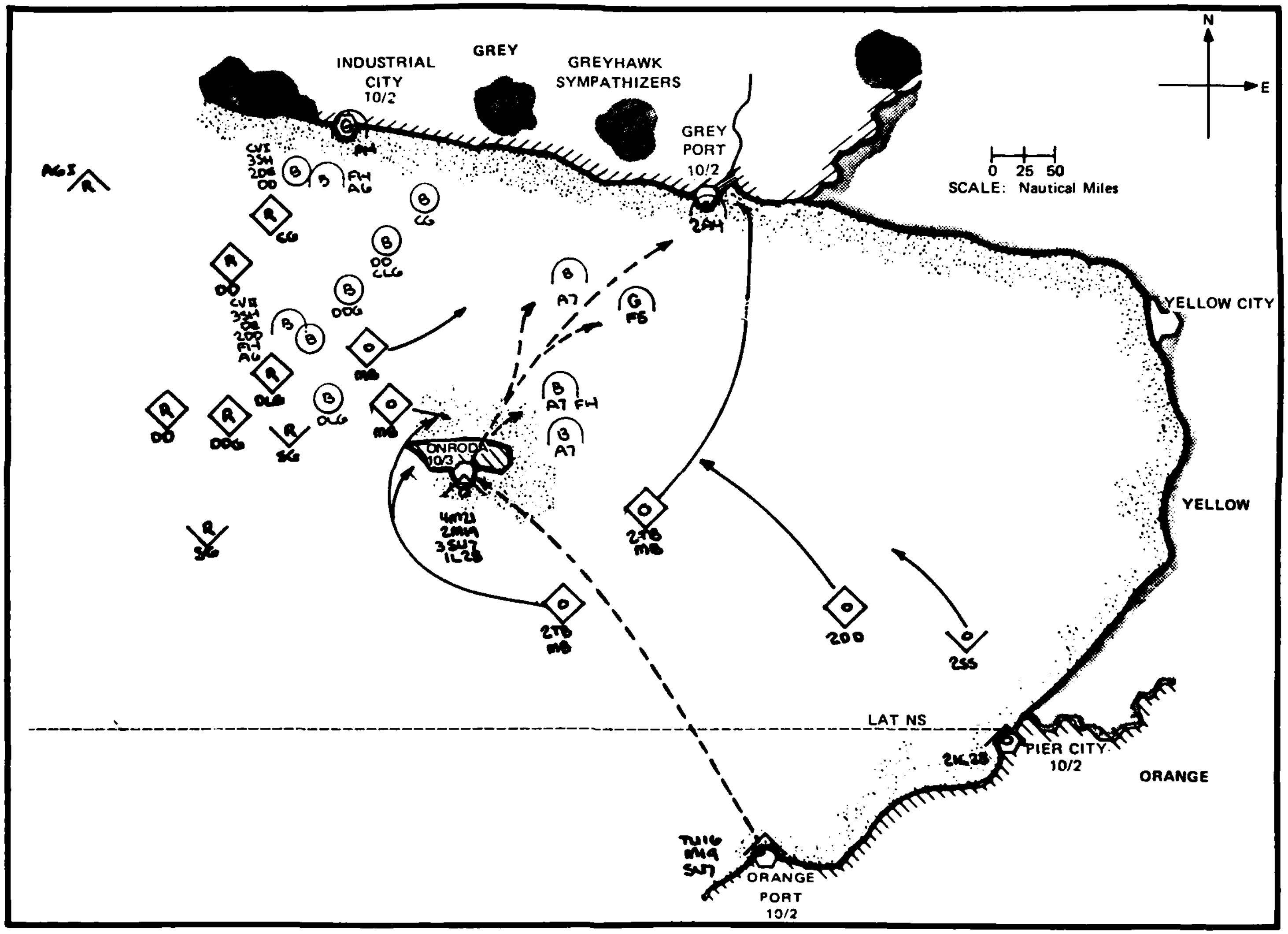


FIGURE 34 ANTICIPATED ORANGE REACTION TO BLOCKADE

3. PROBABILITY OF BLUE/RED WAR:

1 CHANCE IN 1000

C4: TAKING THE POINT OF VIEW OF AN ENEMY COMMANDER, IDENTIFY SCENARIOS THAT MAKE THE ALTERNATIVE "AIR BLOCKADE BETWEEN GREY AND ONRODA" LOOK VERY BAD. SELECT THE SCENARIO OF GREATEST CONCERN TO YOU. USING THE SIMULATION BOARD:

1. TRACE OUT ENEMY FORCE MOVEMENTS UNDER YOUR WORST-CASE SCENARIO AND ESTIMATE ENGAGEMENT LOSSES.

2. REVISE YOUR ACTION PLAN OR WORST-CASE SCENARIO AS NECESSARY IN LIGHT OF SIMULATION RESULTS.

As was the case with air strike, the commander's major concern under the blockade is his vulnerability to an attack by Red. The assumed attack pattern as specified by the commander is shown in Figure 35. Movement assumptions are:

- Red attacks CVI with its three northernmost ships (CG, DD, and DLG)

- Red and Orange launch a coordinated attack against CVII

  - Red attacks CVII with its remaining ships and submarines (2xSG, DD, DDG)

  - Red sends its long-range bomber (TU20) located at Orange Port toward CVII and attacks Blue's southernmost destroyer (DLG)

  - Orange attacks CVII and the destroyer

  - Orange launches a massive air attack (4xMIG21, 2xMIG19, 1xSU7, 1xIL28) against CVII and the destroyer.

Total losses estimated from simulation are shown in Table 8.

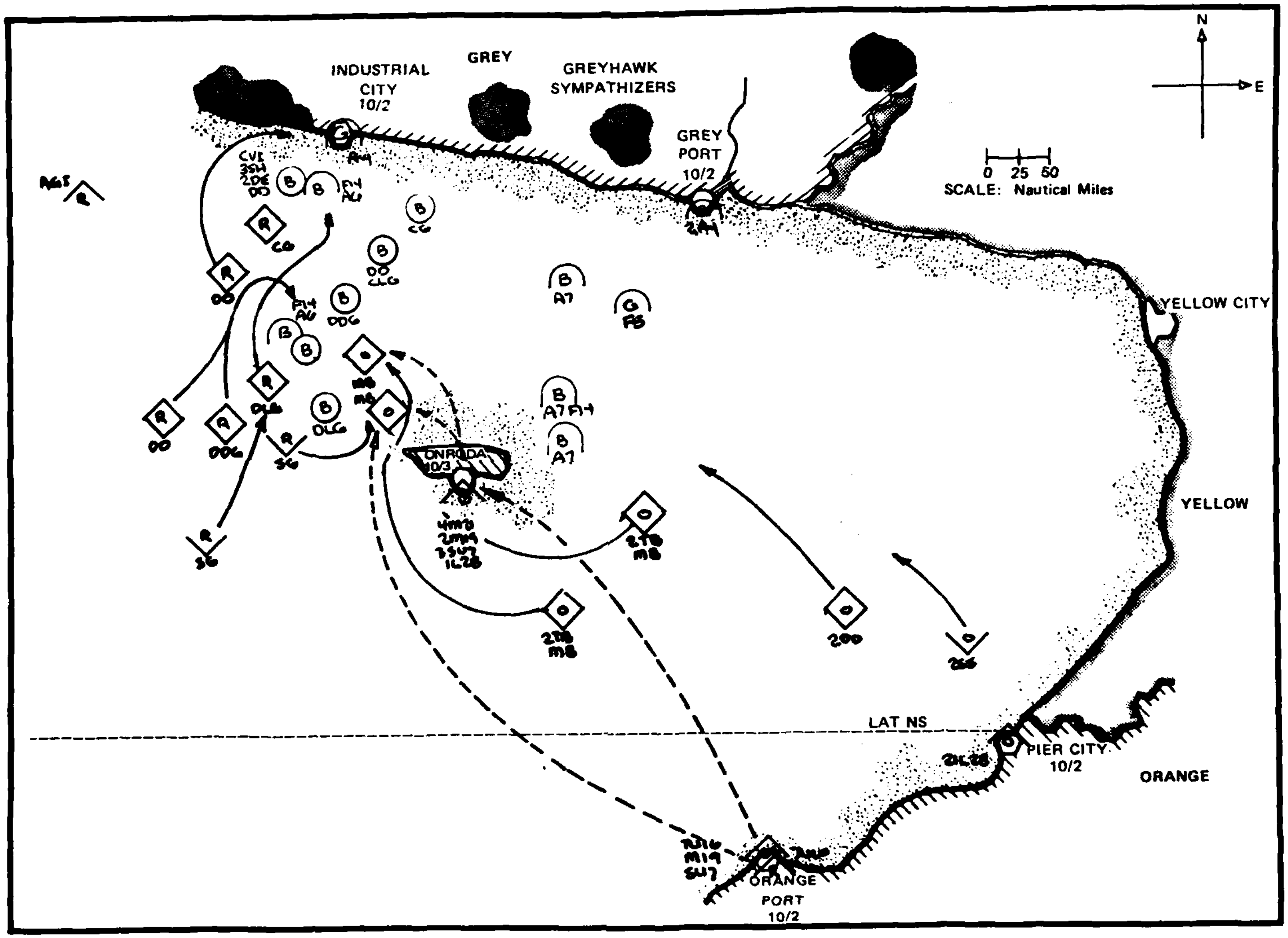


FIGURE 35 WORST-CASE SCENARIO UNDER BLOCKADE: RED ATTACK

Table 8

ESTIMATED LOSSES
BLOCKADE--WORST-CASE SCENARIO

	Aircraft	Ships
Blue	1.16xF14, 1xA7, .33xA6, .5xSH	.16xCV, .33xDLG, .5xDE, .1xDD
Grey	1xF5, 2xF4, 5xA4	2xDD
Orange	11xMIG21, 5xMIG19, 2xSU7	

Lower losses for Blue result from the blockade as compared with those from the air strike alternative. Although the disadvantage of positioning CVII closer to ONRODA is that it allows Orange to use its missile and torpedo boats in the attack, and advantage is that CVI is also closer to its high-power surface units (DDG, CG, and CLG). These units, especially the CLG, divert the attack and prevent a large fraction of the Orange units from reaching the carrier.

C5: TAKING INTO ACCOUNT ALL ASPECTS OF YOUR SITUATION, EVALUATE THE ALTERNATIVE "AIR BLOCKADE BETWEEN GREY AND ONRODA" UNDER THE WORST-CASE SCENARIO

1. NUMBER OF POTENTIAL ORANGE SORTIES:

ORANGE COULD POTENTIALLY LAUNCH ONLY TWO MAJOR AIR STRIKES AGAINST GREY BEFORE ORANGE LOSES THE MAJORITY OF ITS AIR UNITS

2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED:

LIGHT DAMAGE TO CVII, LOSS OF UP TO 30% OF AIRCRAFT

3. PROBABILITY OF BLUE/RED WAR:

1 CHANCE IN 10

3.1.6 Critical Uncertainty Identification

The difference between the anticipated and worst-case scenario is, again, the Red attack.

D1: IF A SIGNIFICANT DIFFERENCE EXISTS BETWEEN THE DESIRABILITY OF TWO SCENARIOS, WHAT EVENT OR EVENTS ARE MOST RESPONSIBLE FOR THE DIFFERENCE?

1. *RED ATTACK*
2.

3.1.7 Alternative Evaluation

C1': ARE THERE OTHER ALTERNATIVE COURSES OF ACTION THAT YOU WISH TO EXPLORE? (IDENTIFY BY NUMBER)

1. AIR STRIKE ONRODA
2. AIR BLOCKADE BETWEEN GREY AND ONRODA
3. DESTROY ONRODA AIRFIELD WITH NAVAL GUNFIRE
4. AMPHIBIOUS LANDING
5. OTHER (SPECIFY)

NO

3.1.8 Summary of Results

Having completed the evaluation of selected alternatives and identified major uncertainties, the program concludes the preliminary structuring phase by presenting the user with options for reviewing the various information that has been input.

E1: SELECT AN ITEM FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW TASK INCENTIVE
2. REVIEW OBJECTIVES AND OUTCOME MEASURES
3. REVIEW LIST OF ALTERNATIVES
4. REVIEW EVALUATION OF ALTERNATIVES
5. TERMINATE PRELIMINARY STRUCTURING PHASE

1

TASK INCENTIVE:

ONRODA HAS BEEN ATTACKED AND OCCUPIED BY ENEMY ORANGE. SURVIVAL OF GREY GOVERNMENT THREATENED BY FURTHER ORANGE AGGRESSION.

E1: SELECT AN ACTION FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW TASK INCENTIVE
2. REVIEW OBJECTIVES AND OUTCOME MEASURES
3. REVIEW LIST OF ALTERNATIVES
4. REVIEW EVALUATION OF ALTERNATIVES
5. TERMINATE PRELIMINARY STRUCTURING PHASE

2

OBJECTIVES AND OUTCOME MEASURES

SUPERIOR'S OBJECTIVES:

SUPPORT GREY IN ITS EFFORTS TO DEFEAT THE REBEL GREYHAWKS AND TO RESIST AN INVASION BY ORANGE.

TASK FORCE OBJECTIVES:

A. NEUTRALIZE THE ORANGE AIR FORCES ON ONRODA ISLAND

OUTCOME MEASURES:

1. NUMBER OF POTENTIAL ORANGE SORTIES
2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED
3. PROBABILITY OF BLUE/RED WAR

E1: SELECT AN ACTION FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW TASK INCENTIVE
2. REVIEW OBJECTIVES AND OUTCOME MEASURES
3. REVIEW LIST OF ALTERNATIVES
4. REVIEW EVALUATION OF ALTERNATIVES
5. TERMINATE PRELIMINARY STRUCTURING PHASE

3

ALTERNATIVES:

1. AIR STRIKE ONRODA FOLLOWED BY BLOCKADE BETWEEN ORANGE AND ONRODA
2. AIR BLOCKADE BETWEEN GREY AND ONRODA
3. DESTROY ONRODA AIRFIELD WITH NAVAL GUNFIRE
4. AMPHIBIOUS LANDING

E1: SELECT AN ACTION FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW TASK INCENTIVE
2. REVIEW OBJECTIVES AND OUTCOME MEASURES
3. REVIEW LIST OF ALTERNATIVES
4. REVIEW EVALUATION OF ALTERNATIVES
5. TERMINATE PRELIMINARY STRUCTURING PHASE

4

ALTERNATIVE EVALUATION:

1. AIR STRIKE ONRODA FOLLOWED BY BLOCKADE BETWEEN ORANGE AND ONRODA

    A. CRITICAL UNCERTAINTIES:

        1. RED ATTACK

    B. OUTCOME MEASURE ESTIMATES:

        1. NUMBER OF POTENTIAL ORANGE SORTIES

            ANTICIPATED:

            ORANGE COULD POTENTIALLY LAUNCH ONLY TWO MAJOR AIR STRIKES AGAINST GREY BEFORE ORANGE LOSES THE MAJORITY OF ITS AIR UNITS.

            WORST-CASE:

            ORANGE COULD POTENTIALLY LAUNCH ONLY TWO MAJOR AIR STRIKES AGAINST GREY BEFORE ORANGE LOSES THE MAJORITY OF ITS AIR UNITS.

        2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED

            ANTICIPATED:

            UP TO 50% OF THE ATTACKING AIRCRAFT

            WORST-CASE:

            SIGNIFICANT DAMAGE TO CVII PLUS LOSS OR DAMAGE OF RELATED SHIPS. LOSS OF UP TO 2/3 OF AIRCRAFT ON CVI.

3. PROBABILITY OF BLUE/RED WAR

ANTICIPATED:

1 CHANCE IN 100

WORST-CASE:

1 CHANCE IN 10

2. AIR BLOCKADE BETWEEN GREY AND ONRODA

A. CRITICAL UNCERTAINTIES:

1. RED ATTACK

B. OUTCOME MEASURE ESTIMATES:

1. NUMBER OF POTENTIAL ORANGE SORTIES

ANTICIPATED:

ORANGE CAN PENETRATE BLOCKADE BUT INCURS HEAVY LOSSES WITH EACH ATTACK

WORST-CASE:

ORANGE CAN PENETRATE BLOCKADE BUT INCURS HEAVY LOSSES WITH EACH ATTEMPT

2. NUMBER AND TYPE OF OWN UNITS DAMAGED OR DESTROYED

ANTICIPATED:

LOW, PROBABLE LOSS OF SEVERAL FIGHTER OR ATTACK AIRCRAFT

WORST-CASE:

MODERATE DAMAGE TO CVII, HEAVY LOSSES TO AIRCRAFT

3. PROBABILITY OF BLUE/RED WAR

ANTICIPATED:

LOW

WORST-CASE:

HIGH

E1: SELECT AN ACTION FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW TASK INCENTIVE
2. REVIEW OBJECTIVES AND OUTCOME MEASURES
3. REVIEW LIST OF ALTERNATIVES
4. REVIEW EVALUATION OF ALTERNATIVES
5. TERMINATE PRELIMINARY STRUCTURING PHASE

5

3.2 Modeling Phase

The modeling phase of the structuring process is designed to produce a simple quantitative model of the user's decision problem. The form of the decision model produced is a decision tree. As explained in Subsection 1.3.3, influence diagrams are closely related to decision trees and are also used in the modeling phase. Although trees are a convenient model form for analysis, experience shows that decision-makers usually find influence diagrams easier to understand. The computer aid therefore uses influence diagrams for communications with the user whenever less detail is required than is captured by the decision tree. In particular, an influence diagram is used as an interim model in the construction of the decision tree: the user constructs an influence diagram representing his decision problem and then relies on the computer to convert the diagram to a decision tree.

Figure 36 shows the structuring functions carried out in the modeling phase.

3.2.1 Problem Review

The user is first given the opportunity to reveiw the problem statement defined in the preliminary structuring phase.

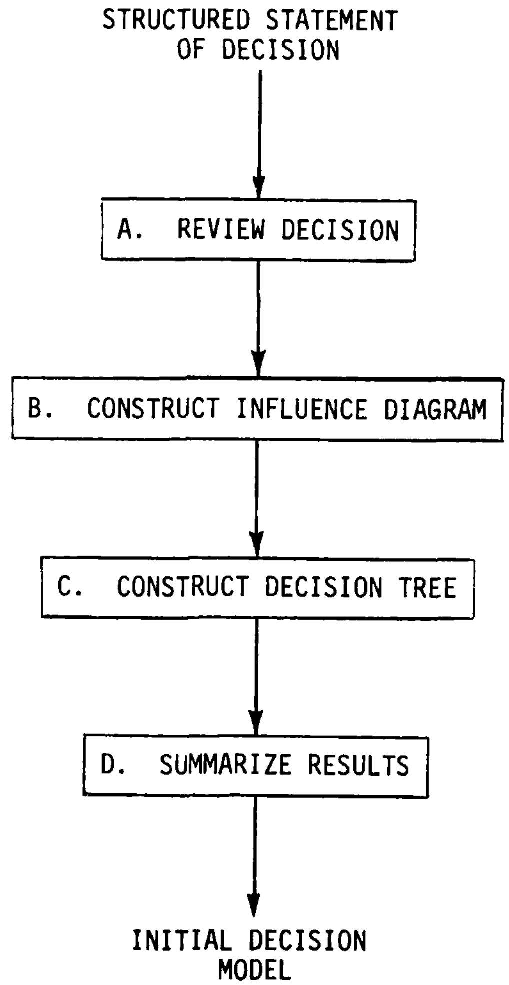


FIGURE 36 FUNCTIONS IN THE MODELING PHASE

A1: DO YOU WISH TO REVIEW THE RESULTS OF THE PRELIMINARY STRUCTURING PHASE?

NO

3.2.2 Influence Diagram Construction

To begin development of the influence diagram, the user must first define short labels for the variables to appear in graphic displays.

B1: PROVIDE A LABEL FOR THE PRIMARY DECISION UNDER CONSIDERATION. (ONLY THE FIRST 9 CHARACTERS OF LABELS APPEAR IN DISPLAYS.)

PRIMARY DECISION: *BLUE ACT*

B2: PROVIDE LABELS FOR EACH DOWNSTREAM DECISION THAT YOU WOULD LIKE TO APPEAR IN THE INFLUENCE DIAGRAM.

DOWNSTREAM DECISION 1:

A downstream decision is a related decision that must be made at a later point in time and that will be made contingent on some information to be received by that later point in time. No downstream decisions have yet been identified in this example.

B3: PROVIDE A LABEL FOR EACH CRITICAL UNCERTAINTY THAT YOU WOULD LIKE TO APPEAR IN THE INFLUENCE DIAGRAM.

CRITICAL UNCERTAINTY 1: *RED ATK*
CRITICAL UNCERTAINTY 2:

Decision variables and uncertain variables have now been defined. The remaining step is to define the outcome variables.

As noted previously, outcome variables and the corresponding value model indicating the relative importance of outcome variables are regarded as inputs to be provided to the structuring aid prior to initiation of a structuring session. The value model is treated as a prestructured input because it has broader applicability than the current decision of concern. In fact, an important purpose of an explicit value model is that its uniform application across a variety of problems provides consistency in trade-off judgments. Logically, then, the value model might be specified and provided to the TFC by his superiors, perhaps, at the time his orders are delivered. The staff analyst could then input the value model during the initialization of the computer program. If it is found desirable to provide the user with greater flexibility in defining the value model, computer programs designed to assist in the model development could be easily added to the aid. A number of computer programs for assisting the elicitation of a value model already exist. (See, for example [23].)

The value model used in most of the applications of the aid to date is a utility function for the ONRODA scenario derived from previous research.* The value or utility of the decision outcome is expressed as a function of four variables representing (1) the degree to which Orange forces on ONRODA have been successfully "neutralized," as ordered in the Fleet Directive, (2) the likelihood that the Blue action will precipitate

*The reference is to initial research conducted by SRI under the ODA program. As described in Section 1.2, to help identify aspects of decision analysis that might be usefully applied to assist naval task force decision-making, a series of sample decision analyses were conducted in which subjects were asked to play the role of the TFC described in the ONRODA scenario. Although the analyses addressed different decisions, in all cases value models were required that specified the TFC's willingness to sacrifice his own forces to obtain mission objectives. To obtain these value models, value encoding techniques developed in previous research by SRI were applied. The particular value model given here was obtained in a sample analysis in which the subject was J. Victor Rowney, a retired Operations Officer in the U.S. navy and coauthor of the ONRODA Warfare Scenario.

a Blue/Red war, (3) the losses sustained to Blue surface units, and (4) the losses sustained to Blue air units. Specifically, outcome value, V, is assumed to be given by the linear, additive equation:

$$V = -0.003z - 912w - 7y - x \quad ,$$

where

z = the number of successful sorties that Orange could launch from ONRODA against Grey during the 12-week period following initiation of the Blue action (measures degree of "neutralization" achieved)

w = the TFC's subjective probability that Blue and Red will declare war during the 12-week period immediately following initiation of his action (measures risk of war)

y = 2.5 times the fraction of Blue cruiser capability lost plus 25 times the fraction of carrier capability lost (this can be interpreted as the total carrier and cruiser ship damage suffered as a result of the Blue action expressed in destroyer ship equivalents)

x = 6 times the number of F14s lost, plus 3 times the number of A6s lost, plus the number of A7s lost (this can be regarded as a measure of total Blue air losses resulting from the Blue action expressed in A7 aircraft equivalents).

The user is given the opportunity to select the outcome variables that he would like to be included in his decision model from those contained in the available value model.

B4: OUTCOME MEASURES AVAILABLE IN THE VALUE MODEL ARE:

1. NUMBER OF POTENTIAL ORANGE SORTIES AGAINST GREY DURING THE NEXT 12-WEEK PERIOD (SORTIES)

2. PROBABILITY THAT BLUE AND RED WILL DECLARE WAR DURING THE NEXT 12-WEEK PERIOD (PROB WAR)

3. FRACTION OF BLUE CARRIER AND CRUISER CAPABILITY DESTROYED (SHIP LOSS)

4. NUMBER AND TYPE OF BLUE FIGHTER AND ATTACK AIRCRAFT DESTROYED (AIR LOSS)

INDICATE BY NUMBER THE OUTCOME MEASURES THAT YOU WOULD LIKE TO APPEAR IN THE INFLUENCE DIAGRAM.

1, 2, 3, 4

OUTCOME MEASURES WILL BE:

1. SORTIES
2. PROB WAR
3. SHIP LOSS
4. AIR LOSS

B5: DECISIONS, CRITICAL UNCERTAINTIES, AND OUTCOME MEASURES ARE REPRESENTED BY THE VARIABLES SHOWN IN THE DISPLAY. SPECIFY THE INFLUENCES AMONG THESE VARIABLES.

The display as it appears at this point in the sample application is shown in Figure 37. Although not shown in the figure, variables are color-coded. Decision variables are shown in blue, uncertain variables in red, and outcome variables in yellow. Explanation of how to specify influences may be obtained by typing *HELP*.

HELP

B5.1: THE INFLUENCE DIAGRAM IS DEFINED USING THE IDENTIFIERS ASSIGNED TO THE VARIABLES IN THE DISPLAY (E.G., A, B, . . .). TO SPECIFY THAT 'A' INFLUENCES 'B' FOR EXAMPLE, TYPE:

'A → B'

OTHER POSSIBLE RESPONSES INCLUDE:

'A → B → C' WHICH MEANS 'A' INFLUENCES 'B' AND 'B' INFLUENCES 'C'

'A → B, C' WHICH MEANS 'A' INFLUENCES 'B' AND 'A' INFLUENCES 'C'

INFLUENCES MAY BE REMOVED BY USING THE SYMBOL'≠' IN PLACE OF '→'. MORE THAN ONE PHRASE MAY APPEAR ON ONE LINE IF THEY ARE SEPARATED BY ';'. A BLANK LINE TERMINATES THE INFLUENCE DIAGRAM DEFINITION.

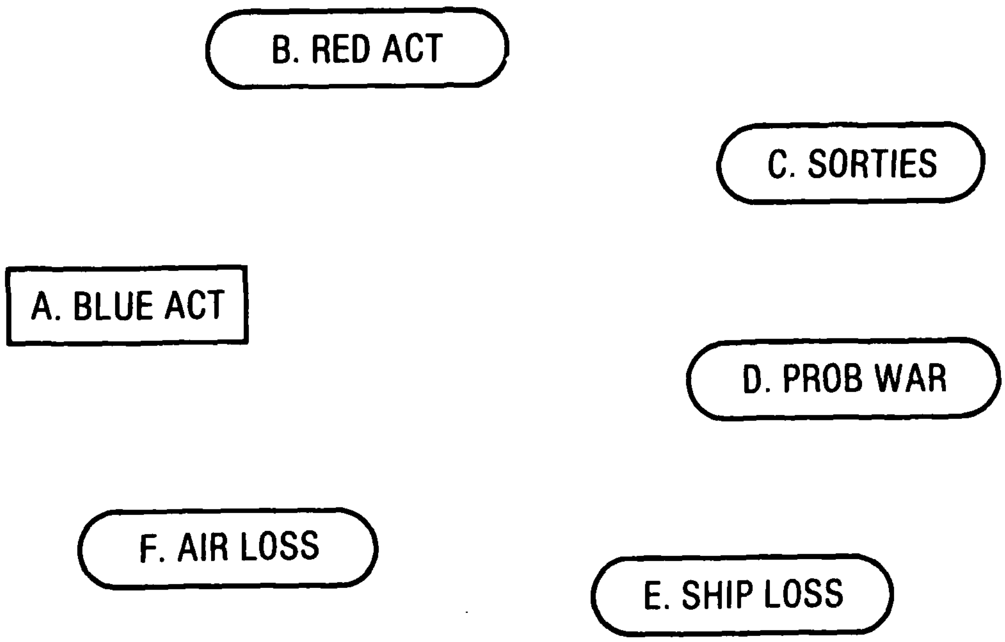


FIGURE 37 DISPLAY PRESENTED TO SYSTEM USER DURING CONSTRUCTION OF INFLUENCE DIAGRAM

B5: DECISIONS, CRITICAL UNCERTAINTIES, AND OUTCOME MEASURES ARE REPRESENTED IN THE DISPLAY. SPECIFY EACH OF THE INFLUENCES.

$A \rightarrow B, C, E, F$; $B \rightarrow D, E, F$;

Figure 38 shows the resulting display. As can be seen by the arrows, the user has specified that air and ship losses depend on both the Blue action and on whether or not Red attacks the task force. The number of potential Orange sorties depends only on Blue action, and the probability of war depends only on whether Red attacks the task force. Whether or not Red attacks, however, depends on the Blue action.

3.2.3 Decision Tree Construction

Not all influence diagrams can be represented as decision trees. Those that can are called decision tree networks and satisfy a specific set of conditions, as described in Subsection 1.3.2. In this structuring function, the computer checks to see if the influence diagram is a decision tree network. If it is not, the computer indicates the difficulty to the user. In this application, the influence diagram is a valid decision tree network. To convert the diagram to a tree, possible "states" are elicited for each variable (alternatives for decisions, outcome values and probabilities for each uncertainty). The computer begins with the "earliest" decision variable in the diagram--one that has no other variables influencing it. Therefore, possible states for BLUE ACT are first established.

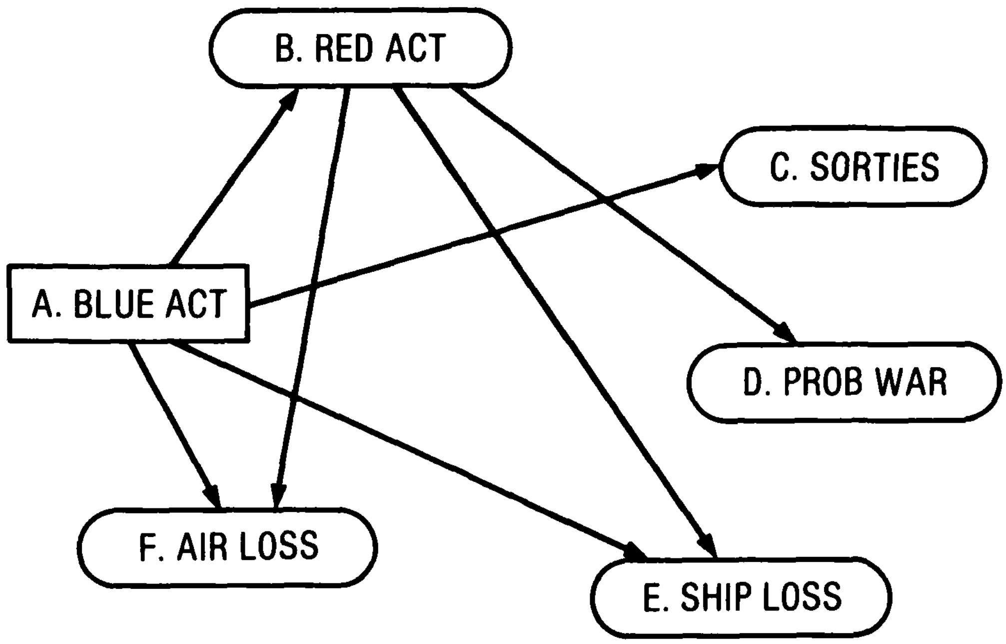


FIGURE 38 INFLUENCE DIAGRAM FOR SAMPLE APPLICATION

C1: PROVIDE A LABEL FOR EACH ALTERNATIVE UNDER CONSIDERATION FOR THE DECISION "BLUE ACT".

ALTERNATIVE 1: *AIRSTRIKE*
ALTERNATIVE 2: *BLOCKADE*
ALTERNATIVE 3:

Next, states for each subsequent variable are elicited.

C2: PROVIDE A LABEL AND PROBABILITY FOR EACH POSSIBLE OUTCOME TO THE UNCERTAINTY LISTED BELOW UNDER EACH ASSUMPTION. A BLANK LABEL WILL INDICATE THAT ALL OUTCOMES HAVE BEEN SPECIFIED.

ASSUMPTION: "BLUE ACT" = "AIR STRIKE"

POSSIBLE OUTCOMES FOR THE UNCERTAINTY "RED ACT":

OUTCOME 1: *RED ATK*
PROBABILITY: *.04*

OUTCOME 2: *NO RED AT*
PROBABILITY: *.96*

OUTCOME 3:

ASSUMPTION: "BLUE ACT" = "BLOCKADE"

POSSIBLE OUTCOMES FOR "RED ACT"

OUTCOME 1: *RED ATK*
PROBABILITY: *.01*

OUTCOME 2: *NO RED AT*
PROBABILITY: *.99*

OUTCOME 3:

The computer formulates and orders these questions based on the form of the influence diagram, and the design is such that only the minimum number of requests for information are made.* Thus, for example, if a variable for which outcomes are being assessed does not have an influencing arrow leading from another variable, then the computer does not ask for outcomes and probabilities conditioned on values for that variable. The computer now displays the structure of the decision tree (see Figure 39). To complete the tree, values must be assigned to each outcome measure for each path through the tree. The computer asks the user to enter best, low, and high estimates for the expected value of each of the outcome measures that have been specified for evaluating the decision.

```
C3:  EACH PATH THROUGH THE DECISION TREE CORRESPONDS TO A SCENARIO.
     ENTER YOUR BEST, LOW, AND HIGH ESTIMATES FOR THE EXPECTED
     VALUES OF EACH OUTCOME MEASURE UNDER EACH SCENARIO.  IF YOUR
     ESTIMATES FOR A GIVEN SCENARIO ARE THE SAME AS SPECIFIED IN A
     PREVIOUS SCENARIO, TYPE "USE X", WHERE X IS THE NUMBER OF THE
     PREVIOUS SCENARIO.

     SCENARIO 1: "BLUE ACT" = "AIRSTRIKE"
                 "RED ACT"  = "RED ATK"

        A. "SORTIES"   (BEST, LOW, HIGH EST.): 156, 108, 204
        B. "PROB WAR"  (BEST, LOW, HIGH EST.): .1, .01, .2
        C. "SHIP LOSS"
             "CG"      (BEST, LOW, HIGH EST.): .1, 0, .5
             "CV"      (BEST, LOW, HIGH EST.): 1, .5, 1.1
        D. "AIR LOSS"
             "F14"     (BEST, LOW, HIGH EST.): 12, 8, 24
             "A7"      (BEST, LOW, HIGH EST.): 12, 8, 36
             "A6"      (BEST, LOW, HIGH EST.): 8, 4, 18
```

---

* As described in Subsection 1.3.2, variables are addressed in the order in which they appear in the influence diagram. Thus, all of the predecessors to a variable (variables with arrows leading to the variable under consideration) will have had their possible states specified before the states of the new variables are requested. To specify the states of the new variable, the immediate predecessors (variables with arrows going directly to the variable under consideration) are set equal to each possible specification of their states, in turn.

```
SCENARIO 2: "BLUE ACT" = "AIRSTRIKE"
            "RED ACT"  = "NO RED AT"

   A. "SORTIES"   (BEST, LOW, HIGH EST.): 156, 108, 204 (Y/N?)Y
   B. "PROB WAR"  (BEST, LOW, HIGH EST.): .01, .001, .02
   C. "SHIP LOSS"
         "CG"     (BEST, LOW, HIGH EST.): 0, 0, 0
         "CV"     (BEST, LOW, HIGH EST.): 0, 0, 0
   D. "AIR LOSS"
         "F14"    (BEST, LOW, HIGH EST.): 8, 2, 16
         "A7"     (BEST, LOW, HIGH EST.): 8, 2, 24
         "A6"     (BEST, LOW, HIGH EST.): 4, 2, 12

SCENARIO 3: "BLUE ACT" = "BLOCKADE"
            "RED ACT"  = "RED ATK"

   A. "SORTIES"   (BEST, LOW, HIGH EST.): 168, 120, 204
   B. "PROB WAR"  (BEST, LOW, HIGH EST.): .1, .01, .2 (Y/N?)Y
   C. "SHIP LOSS"
         "CG"     (BEST, LOW, HIGH EST.): USE 1
         "CV"     (BEST, LOW, HIGH EST.): .5, .1, 1
   D. "AIR LOSS"
         "F14"    (BEST, LOW, HIGH EST.): 12, 8, 16
         "A7"     (BEST, LOW, HIGH EST.): USE 1
         "A6"     (BEST, LOW, HIGH EST.): USE 1

SCENARIO 4: "BLUE ACT" = "BLOCKADE"
            "RED ACT"  = "NO RED AT"

   A. "SORTIES"   (BEST, LOW, HIGH EST.): 168, 120, 204 (Y/N?)Y
   B. "PROB WAR"  (BEST, LOW, HIGH EST.): .01, .001, .02 (Y/N?)Y
   C. "SHIP LOSS"
         "CG"     (BEST, LOW, HIGH EST.): USE 2
         "CV"     (BEST, LOW, HIGH EST.): USE 2
   D. "AIR LOSS"
         "F14"    (BEST, LOW, HIGH EST.): 6, 2, 10
         "A7"     (BEST, LOW, HIGH EST.): 6, 2, 18
         "A6"     (BEST, LOW, HIGH EST.): 2, 0, 12
```

Notice in the above that the computer simplifies data input requirements by again using the influence diagram to identify when conditioning information is and is not important. When the influence diagram shows an outcome variable not to be influenced by a model variable, the computer does not repeat the request for outcome estimates for each value of that model variable. Instead, it merely asks the user to confirm that the previously entered values are appropriate. For example, Scenario 1 is identical to Scenario 2 except that Red attacks in the first scenario and not in the second. The influence diagram shows that "SORTIES" does not depend on "RED ACT." Therefore, when requesting estimates for the outcome "SORTIES" in Scenario 2, the computer prints the outcome values that were input for Scenario 1 and asks the user to confirm with a "Y" that these same estimates hold for Scenario 2.

The final step in the Modeling Phase is to solve the decision tree and to identify the path through the tree whose uncertainty is most critical to the decision. To accomplish this, the computer first fits probability distributions to the outcome measure estimates. (Fitted distributions may be displayed as was shown in Figure 16.) The fitting method is based on splines and is such that the best estimate is the median, the low and high estimates are the 10% and 90% points of the fitted distribution, and the 0% and 100% points on the distribution are the absolute minimum and maximum values specified by the domain of the value function. The computer then calculates the distribution on overall outcome value for each path through the tree, solves the tree to identify the decision strategy that maximizes expected value, and then calculates the value of resolving uncertainty in outcome value for each path through the tree (using the usual value of information calculation [25]). The value of further modeling for a given path through the tree is defined as the expected value of eliminating the outcome uncertainty associated with that path.*

---

*A description of the computation and the logic behind it is given in previous SRI reports [15, 16] and is not repeated here.

Figure 39 illustrates the manner in which the computer summarizes results. The display shows the decision tree and the decision strategy with the highest expected value and indicates the value of further modeling at each node in the decision tree. The value of further modeling assigned to a given node is the value (expressed in units of the value function) of eliminating residual outcome uncertainty given the events represented by the branches leading to that node. The computer highlights the path with the highest value of further modeling by coloring this path red.

3.2.4 Summary of Results

The program concludes the modeling phase by presenting the user the option to review the various elements of the decision model.

```
D1:  SELECT AN ITEM FROM THE MENU (INDICATE BY NUMBER):

          1.  REVIEW INFLUENCE DIAGRAM
          2.  REVIEW DECISION TREE
          3.  REVIEW OUTCOME MEASURE ESTIMATES
          4.  TERMINATE MODELING PHASE

3

     OUTCOME MEASURE ESTIMATES:

          SCENARIO 1: "BLUE ACT" = "AIRSTRIKE"
                      "RED ACT"  = "RED ATK"
```

	BEST ESTIMATE	LOW ESTIMATE	HIGH ESTIMATE
A. "SORTIES"	156	108	204
B. "PROB WAR"	.1	.01	.2
C. "SHIP LOSS"			
"CG"	.1	0	.5
"CV"	1	.5	1.1
D. "AIR LOSS"			
"F14"	12	8	24
"A7"	12	8	36
"A6"	8	4	18

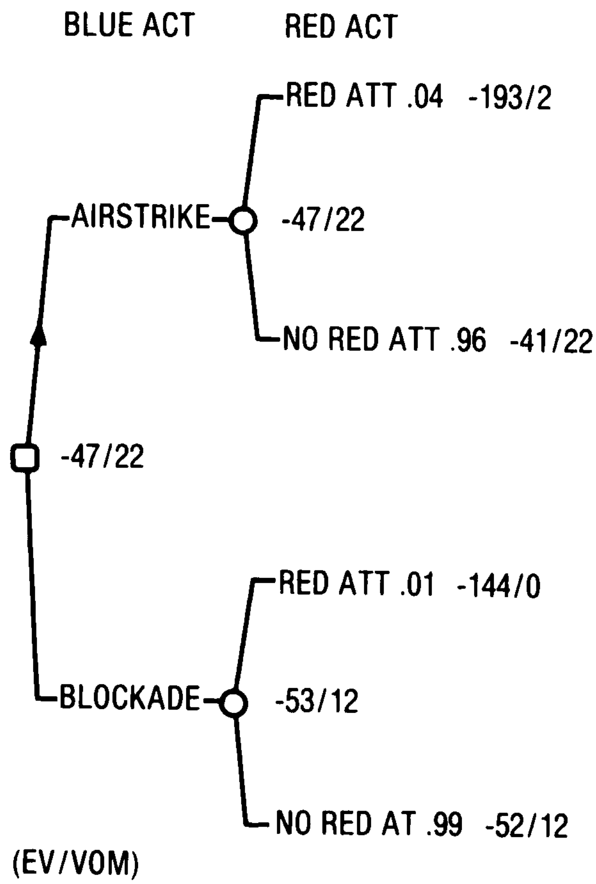


FIGURE 39 DECISION TREE FOR SAMPLE APPLICATION AS DISPLAYED IN THE MODELING PHASE

SCENARIO 2: "BLUE ACT" = "AIR STRIKE"
"RED ACT" = "NO RED AT"

	BEST ESTIMATE	LOW ESTIMATE	HIGH ESTIMATE
A. "SORTIES"	156	108	204
B. "PROB WAR"	.01	.001	.02
C. "SHIP LOSS"			
"CG"	0	0	0
"CV"	0	0	0
D. "AIR LOSS"			
"F14"	8	2	16
"A7"	8	2	24
"A6"	4	2	12

SCENARIO 3: "BLUE ACT" = "BLOCKADE"
"RED ATK" = "RED ATK"

A. "SORTIES"	168	120	204
B. "PROB WAR"	.1	.01	.2
C. "SHIP LOSS"			
"CG"	.1	0	.5
"CV"	.5	.1	1
D. "AIR LOSS"			
"F14"	12	8	24
"A7"	12	8	36
"A6"	8	4	18

SCENARIO 4: "BLUE ACT" = "BLOCKADE"
"RED ATK" = "NO RED AT"

A. "SORTIES"	156	108	204
B. "PROB WAR"	.01	.001	.02
C. "SHIP LOSS"			
"CG"	0	0	0
"CV"	0	0	0
D. "AIR LOSS"			
"F14"	6	2	10
"A7"	6	2	18
"A6"	2	0	12

D1: SELECT AN ITEM FROM THE MENU (INDICATE BY NUMBER):

1. REVIEW INFLUENCE DIAGRAM
2. REVIEW DECISION TREE
3. REVIEW OUTCOME MEASURE ESTIMATES
4. TERMINATE MODELING PHASE

4

3.3 Expansion Phase

In the expansion phase, the simple decision model produced in the modeling phase is expanded to include additional factors that affect the decision. The computer aid serves two purposes in this phase. First, it assists the user in identifying critical events that have thus far been omitted from consideration. Second, it simplifies model expansion by providing tests to eliminate newly identified events whose explicit consideration will not significantly affect the decision and, as in the modeling phase, by simplifying the construction of influence diagrams and the construction and evaluation of decision trees. Figure 40 shows the functions executed in the expansion phase.

3.3.1 Problem Review

The user is first given the opportunity to review the current model.

A1: DO YOU WISH TO REVIEW THE RESULTS OF THE MODELING PHASE?

NO

3.3.2 Identification of Critical Events That Have Been Omitted from Analysis

To aid the user in the identification of critical events, the computer composes questions that focus on areas of the current model where the VOM (value of modeling) is the highest. The computer generates the questions by computing the sensitivity of the decision to the uncertainty in each outcome variable for the path through the tree with the highest value of modeling. (See Ref. [15].) In this example, there are four outcome variables: the number of potential Orange sorties following Blue action, the probability of Blue/Red war, Blue ship losses, and Blue

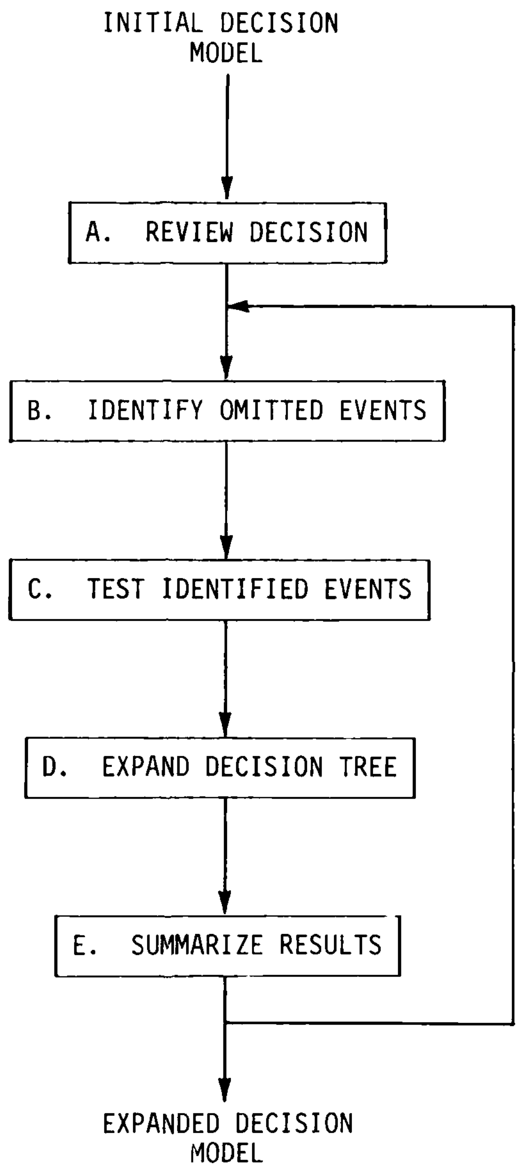


FIGURE 40 FUNCTIONS IN THE EXPANSION PHASE

aircraft losses. Sensitivity analysis shows that uncertainty on Blue aircraft losses contributes most to the high VOM for this example. Since the path through the tree with the highest VOM is air strike followed by no Red attack and aircraft loss is the most sensitive outcome variable, the computer generates the following question designed to help identify missing events:

```
B1:  SUPPOSE YOU CHOOSE THE ALTERNATIVE "AIRSTRIKE" AND THE
     EVENT "NO RED AT" OCCURS.  IS THERE ANY EVENT NOT YET
     INCLUDED IN THE MODEL THAT COULD CAUSE "AIR LOSS" TO
     INCREASE?  (A VALUE OF 58 WOULD BE SUFFICIENT TO PRODUCE
     A DECISION SWITCH)
```

YES

In this sample application, the user identified an event that could lead to significantly larger aircraft losses. The event is that Red may have installed sophisticated antiaircraft surface-to-air missile (SAM) batteries on ONRODA Island. If this is the case, more planes would be lost in the attack against ONRODA than originally estimated. If the user had been unable to identify an event that could cause aircraft losses to be significantly higher, i.e., if he had answered *NO*, the computer would have composed a similar question based on the second most sensitive outcome variable (probability of Blue/Red war, in this case). Additional questions are composed in this way (continuing with the path through the tree with the second, third, etc., highest value of modeling) until a new event is successfully identified.

Because the answer is affirmative, the computer requests a description and a short label for the newly identified event.

B2: DESCRIBE THE EVENT AND PROVIDE A LABEL FOR IT. (ONLY THE FIRST 9 CHARACTERS OF LABELS WILL APPEAR IN DISPLAYS.)

EVENT DESCRIPTION: *RED SAM BATTERIES ON ONRODA*
EVENT LABEL: *SAM SITES*

3.3.3 Event Testing

Each event proposed for addition to the decision tree is tested to determine if its addition might have sufficient impact on the model to influence results. Testing newly identified events before including them in the model avoids modeling effort in those cases where the effort would not affect the recommended decision strategy. Because of the many outcome assessments that are typically required, adding events to the decision tree can be time-consuming. The most basic test is to ask whether the user would alter his decision if he knew for certain the event would occur:

C1: IF YOU KNEW FOR SURE THE EVENT "SAM SITES" WOULD OCCUR, WOULD YOU LIKELY PREFER SOME ALTERNATIVE OTHER THAN "AIRSTRIKE"?

YES

If the user would not alter his decision under certainty, there is no point to adding the new event to the decision model--regardless of its probability, the event will not affect the recommended alternative.

The second test is to see if the event has sufficient impact on outcomes, in view of its probability, to affect the decision. To minimize the number of data requests, the user is first asked to indicate which scenarios and which outcome variables the newly identified event affects, and revised outcome estimates are then requested only for those outcome variables and scenarios.

C2: WHICH OF THE FOLLOWING SCENARIOS MIGHT BE SIGNIFICANTLY AFFECTED BY THE EVENT "SAM SITES"? (INDICATE BY NUMBER)

1. SCENARIO 1: "BLUE ACT" = "AIRSTRIKE"
   "RED ACT" = "RED ATK"

2. SCENARIO 2: "BLUE ACT" = "AIRSTRIKE"
   "RED ACT" = "NO RED AT"

3. SCENARIO 3: "BLUE ACT" = "BLOCKADE"
   "RED ACT" = "RED ATK"

4. SCENARIO 4: "BLUE ACT" = "BLOCKADE"
   "RED ACT" = "NO RED AT"

1, 2

WHICH OUTCOME MEASURES MIGHT BE SIGNIFICANTLY AFFECTED BY THE EVENT "SAM SITES"? (INDICATE BY NUMBER)

1. "SORTIES"
2. "PROB WAR"
3. "SHIP LOSS"
4. "AIR LOSS"

4

The test estimates the probability of the event and the magnitude of the impact of the event on the outcome measures.

ROUGHLY, WHAT IS THE PROBABILITY OF THE EVENT "SAM SITES"?

.3

IF YOU KNEW FOR CERTAIN THE EVENT "SAM SITES" WOULD OCCUR, INDICATE HOW YOUR ESTIMATES OF THE OUTCOMF MEASURES WOULD CHANGE UNDER EACH SCENARIO. (INDICATE BY NUMBER)

SCENARIO 1: "BLUE ACT" = "AIRSTRIKE"
"RED ACT" = "RED ATK"

THE CURRENT ESTIMATE FOR "AIR LOSS" IS: 48

IF THE EVENT "SAM SITES" OCCURS, THE VALUE
WOULD BE:

1. MUCH LOWER (LESS THAN 16)*
2. LOWER (BETWEEN 16 AND 39)
3. ABOUT THE SAME (BETWEEN 39 AND 59)
4. HIGHER (BETWEEN 59 AND 90)
5. MUCH HIGHER (ABOVE 90)

4

SCENARIO 2: "BLUE ACT" = "AIRSTRIKE"
"RED ACT" = "NO RED AT"

THE CURRENT ESTIMATE FOR "AIR LOSS" IS: 22

IF THE EVENT "SAM SITES" OCCURS, THE VALUE
WOULD BE:

1. MUCH LOWER (LESS THAN 6)
2. LOWER (BETWEEN 6 AND 15)
3. ABOUT THE SAME (BETWEEN 15 AND 30)
4. HIGHER (BETWEEN 30 AND 49)
5. MUCH HIGHER (ABOVE 49)

4

The user has indicated that the event SAM SITES is relevant only under the air strike alternative and that in this case only his aircraft losses will be affected. Specifically, the occurrence of SAM SITES will likely result in aircraft losses moderately higher than originally estimated.

The computer now solves the decision tree assuming that with probability .3 the impacted outcome measures take on values from the ranges that have just been defined, and all other outcome measures take on

---

*The ranges appearing in this question are derived from the probability distribution that has been fit to the outcome measure. Specifically, the ranges are, respectively, the 10% tail, the 10% to 35% interval, the 35% to 65% interval, the 65% to 90% interval, and the 90% tail.

conservative values near the means of their respective probability distributions.* If the currently optimal alternative, AIRSTRIKE, proves not to be the alternative with the highest expected value, there is a reasonable chance that expanding the tree to include the new event may result in a different recommended alternative, and the user is informed that the event should be added to the decision tree.

C3: ANALYSIS INDICATES THAT RELIABILITY OF THE DECISION
    MODEL WILL BE IMPROVED IF THE DECISION TREE IS
    EXPANDED TO INCLUDE THE NEW EVENT.

3.3.4 Expanding the Decision Tree

As in the modeling phase, influence diagrams are used to simplify the development of an expanded decision tree. The first step in the expansion function is to identify each new event that should be added to the existing model.

D1: PROVIDE A LABEL FOR EACH NEW CRITICAL UNCERTAINTY THAT
    YOU WOULD LIKE TO BE ADDED TO THE INFLUENCE DIAGRAM.

        CRITICAL UNCERTAINTY 1: *SAM SITES*
        CRITICAL UNCERTAINTY 2:

Experimental applications have shown that consideration of newly identified events often results in the spontaneous creation of new alternatives or contingency plans for mitigating the adverse consequences associated with that event [14]. Therefore, the user is given the opportunity to specify

*To reduce the chance of incorrectly identifying an event as unimportant, conservative values are selected. For impacted outcome measures, the extreme end value of the specified range is selected unless the specified range is MUCH LOWER or MUCH HIGHER, in which case the absolute minimum or absolute maximum would be selected, respectively. For nonimpacted outcome measures, the most conservative high or low value from the ABOUT THE SAME range (35% or 65% point on the distribution) is selected.

a contingency or downstream decision to be made should the event occur. In this sample application, however, the user believes that the occurrence of the event SAM SITES would not cause him to face any additional decisions.

```
D2:  PROVIDE LABLES FOR EACH DOWNSTREAM DECISION THAT
     YOU WOULD LIKE TO BE ADDED TO THE INFLUENCE DIAGRAM.

          DOWNSTREAM DECISION 1:
```

The computer draws the existing influence diagram and newly proposed variables (Figure 41) and asks the user to specify arrows showing the influences on or resulting from the new variables (Figure 42):

```
D3:  SPECIFY THE INFLUENCES BETWEEN THE NEW VARIABLES AND
     THE VARIABLES IN THE EXISTING INFLUENCE DIAGRAM.

G → F
```

Converting the influence diagram to a decision tree proceeds exactly as in the Modeling Phase.

```
D4:  PROVIDE A LABEL AND PROBABILITY FOR EACH POSSIBLE OUTCOME
     TO THE UNCERTAINTY LISTED BELOW UNDER EACH ASSUMPTION AS
     REQUESTED.  A BLANK LABEL WILL INDICATE THAT ALL OUTCOMES
     HAVE BEEN SPECIFIED.

     POSSIBLE OUTCOMES FOR THE UNCERTAINTY "SAM SITES":

          OUTCOME 1:     SAMS
          PROBABILITY:   .35

          OUTCOME 2:     NO SAMS
          PROBABILITY:   .65

          OUTCOME 3:
```

(See Figure 43 for a display of the tree structure.)

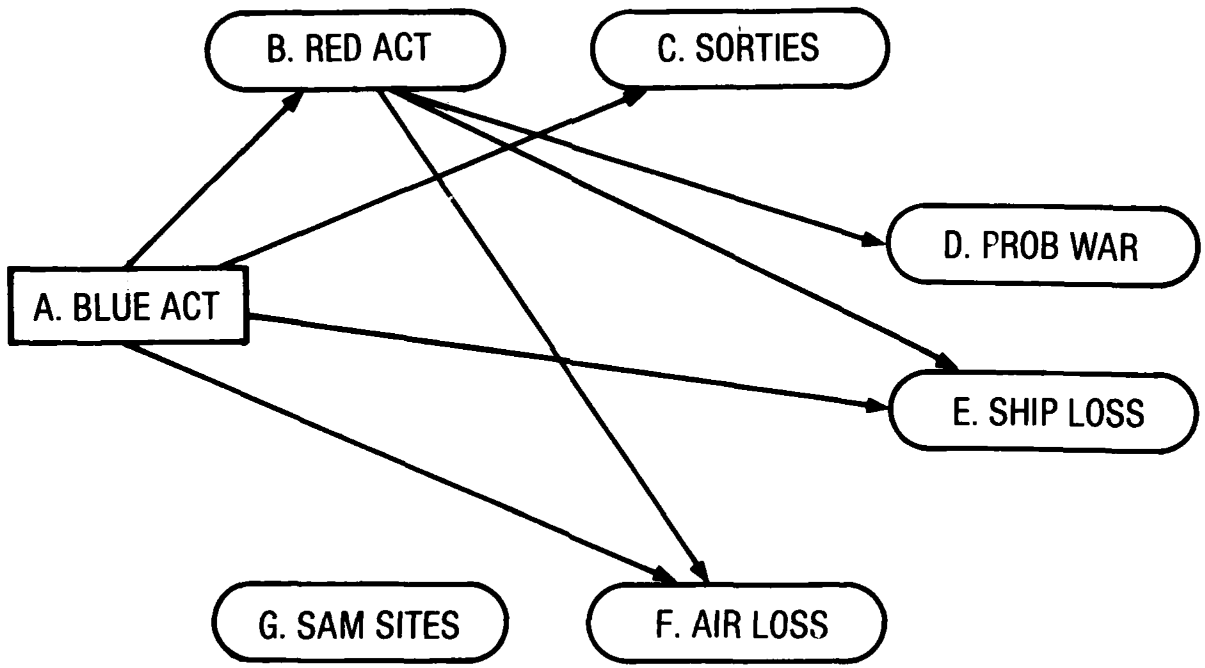


FIGURE 41 DISPLAY PRESENTED FOR EXPANSION OF THE INFLUENCE DIAGRAM

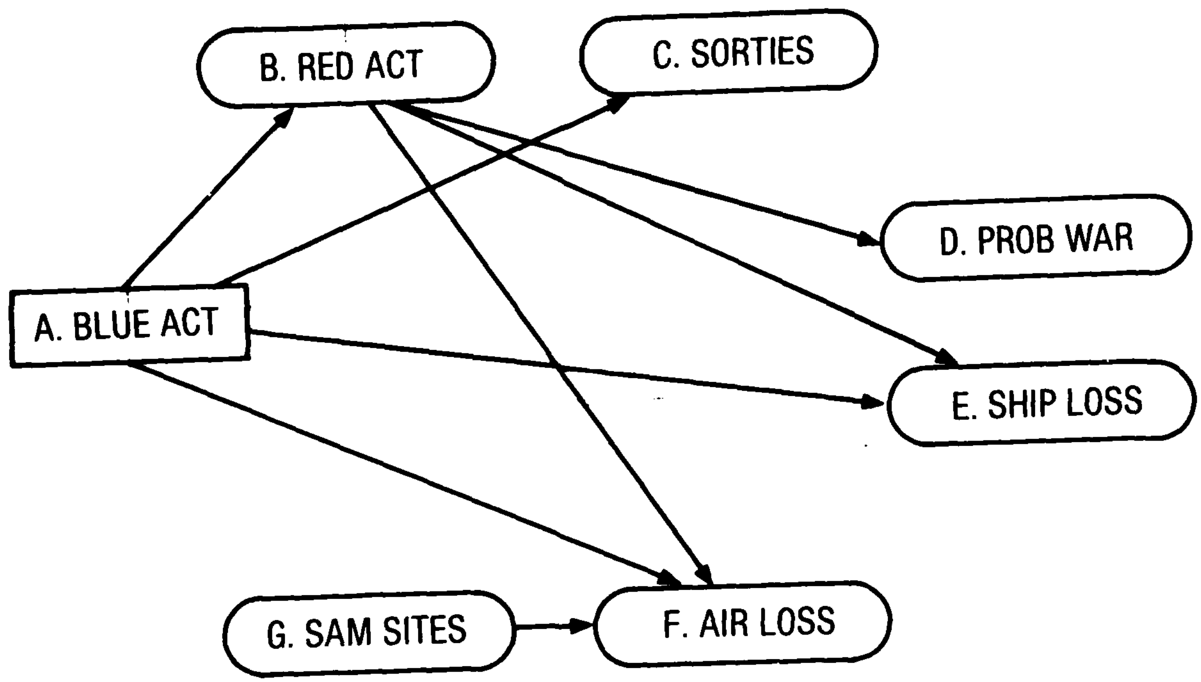


FIGURE 42 EXPANDED INFLUENCE DIAGRAM FOR SAMPLE APPLICATION

D5: DO YOU WISH TO REVIEW PREVIOUS OUTCOME ESTIMATES BEFORE UPDATING THESE ESTIMATES?

YES

OUTCOME ESTIMATES:

SCENARIO 1: "BLUE ACT" = "AIRSTRIKE"
"RED ACT" = "RED ATK"

	BEST ESTIMATE	LOW ESTIMATE	HIGH ESTIMATE
A. "SORTIES"	156	108	204
B. "PROB WAR"	.1	.01	.2
C. "SHIP LOSS"			
"CG"	.1	0	.5
"CV"	1	.5	1.1
D. "AIR LOSS"			
"F14"	12	8	24
"A7"	12	8	36
"A6"	8	4	18

SCENARIO 2: "BLUE ACT" = "AIRSTRIKE"
"RED ACT" = "NO RED AT"

A. "SORTIES"	156	108	204
B. "PROB WAR"	.01	.001	.02
C. "SHIP LOSS"			
"CG"	0	0	0
"CV"	0	0	0
D. "AIR LOSS"			
"F14"	8	2	16
"A7"	8	2	24
"A6"	4	2	12

SCENARIO 3: "BLUE ACT" = "BLOCKADE"
"RED ACT" = "RED ATK"

A. "SORTIES"	168	120	204
B. "PROB WAR"	.1	.01	.2
C. "SHIP LOSS"			
"CG"	.1	0	.5
"CV"	.5	.1	1
D. "AIR LOSS"			
"F14"	12	8	24
"A7"	12	8	36
"A6"	8	4	18

SCENARIO 4: "BLUE ACT" = "BLOCKADE"
"RED ACT" = "NO RED AT"

	BEST ESTIMATE	LOW ESTIMATE	HIGH ESTIMATE
A. "SORTIES"	156	108	204
B. "PROB WAR"	.01	.001	.02
C. "SHIP LOSS"			
"CG"	0	0	0
"CV"	0	0	0
D. "AIR LOSS"			
"F14"	6	2	10
"A7"	6	2	18
"A6"	2	0	12

Notice that revised outcome measurement estimates are not requested when the influence diagram indicates the new variable has no influences and that requests are not made for alternatives that the user indicated in the event testing are not impacted.

D6: EACH PATH THROUGH THE DECISION TREE CORRESPONDS TO A SCENARIO. ENTER YOUR BEST, LOW, AND HIGH ESTIMATES FOR THE EXPECTED VALUES OF EACH OUTCOME MEASURE UNDER EACH SCENARIO. IF YOUR ESTIMATES FOR A GIVEN SCENARIO ARE THE SAME AS SPECIFIED IN A PREVIOUS SCENARIO, TYPE "USE X", WHERE X IS THE NUMBER OF THE PREVIOUS SCENARIO.

SCENARIO 1': "BLUE ACT" = "AIRSTRIKE"
"RED ACT" = "RED ATK"
"SAM SITES" = "SAMS"

A. "AIR LOSS"
"F14" (BEST, LOW, HIGH EST.): *16, 12, 36*
"A7" (BEST, LOW, HIGH EST.): *16, 12, 48*
"A6" (BEST, LOW, HIGH EST.): *12, 6, 27*

SCENARIO 2': "BLUE ACT" = "AIRSTRIKE"
"RED ACT" = "RED ATK"
"SAM SITES" = "NO SAMS"

A. "AIR LOSS"
"F14" (BEST, LOW, HIGH EST.): *USE 1*
"A7" (BEST, LOW, HIGH EST.): *USE 2*
"A6" (BEST, LOW, HIGH EST.): *USE 1*

```
SCENARIO 3': "BLUE ACT"  = "AIRSTRIKE"
             "RED ACT"   = "NO RED AT"
             "SAM SITES" = "SAMS"

    A. "AIR LOSS"
          "F14"    (BEST, LOW, HIGH EST.): 12, 8, 16
          "A7"     (BEST, LOW, HIGH EST.): 12, 8, 16
          "A6"     (BEST, LOW, HIGH EST.): 8, 4, 18

SCENARIO 4': "BLUE ACT"  = "AIRSTRIKE"
             "RED ACT"   = "NO RED AT"
             "SAM SITES" = "NO SAMS"

    A. "AIR LOSS"
          "F14"    (BEST, LOW, HIGH EST.): USE 3
          "A7"     (BEST, LOW, HIGH EST.): USE 3
          "A6"     (BEST, LOW, HIGH EST.): USE 3
```

Figure 43 shows the results of analyzing the expanded decision tree, as they are displayed on the color monitor. The preferred alternative now appears to be BLOCKADE. The path through the tree with the highest value of further modeling is now BLOCKADE followed by NO RED ATK.

3.3.5 Summary of Results

One iteration of the expansion cycle is now complete. The user may now choose to continue the expansion process, review and modify the existing model, or terminate the expansion phase. In this sample application, the user observed that the highest value of further modeling has now been reduced to about 50% of its previous value and is now only about 10% of the absolute value of the decision. For this reason, the user elected to terminate structuring activity at this point.

```
E1:  SELECT AN ITEM FROM THE MENU (INDICATE BY NUMBER):

          1.  REVIEW INFLUENCE DIAGRAM
          2.  REVIEW DECISION TREE
          3.  REVIEW OUTCOME MEASURE ESTIMATES
          4.  CONTINUE EXPANSION
          5.  TERMINATE EXPANSION PHASE

5
```

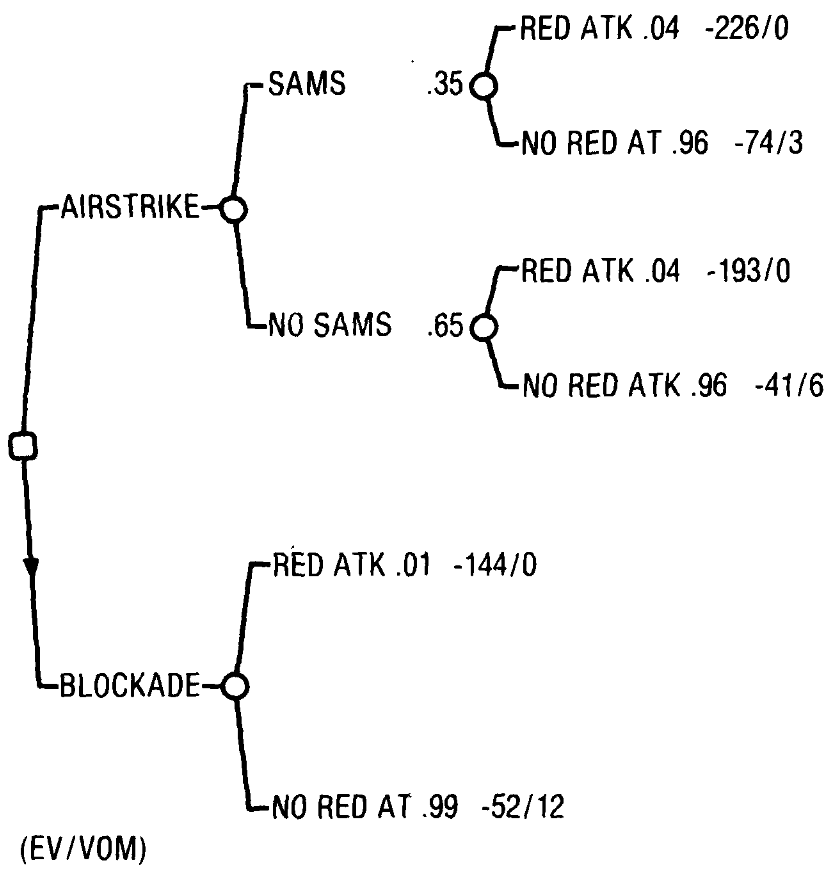


FIGURE 43 EXPANDED DECISION TREE FOR SAMPLE APPLICATION

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

In recent years, the available software to support decision analysis has increased substantially. SRI International, for example, has developed several successful decision analysis software packages, some of which are available to the public from time-sharing services or are sold commercially [26, 27]. Despite the increasing use of such programs, existing software tends to address rather technical aspects of decision analysis and generally requires considerable experience to be properly operated. Development of a comprehensive computer-aided decision structuring system of the type described in this report is a far more ambitious effort than has been previously undertaken.

We had hoped, as part of the ODA Program, that a series of independent tests would be conducted of the pilot decision structuring system. The results of such tests may have provided a much better estimate of the adequacy of current technology as the basis for a practical comprehensive system of automated structuring aids for use by nonspecialists. Unfortunately, the ODA Program was terminated prior to formal testing of the structuring aid. Therefore, results are less conclusive than they might otherwise have been.

There is little doubt that the computer-aided structuring process desribed in this report is of considerable value to professional decision analysts. Applications of the structuring process to practical problems conducted by members of the SRI Decision Analysis Department have been quite successful. Analysts report the aid is especially useful in speeding up pilot analyses (quick, highly simplified analyses conducted to help scope a major decision analysis project). Other practitioners have found the underlying algorithms on which the process is based useful. For example, the process was recently applied by another ODA contractor to navy emission control planning [28], and the expansion algorithm from the structuring process was used by another research team in an analysis of beef cattle production [29].

Most encouraging in assessing the potential value of the computer aid for implementing the structuring process are its basic characteristics. The aid:

- Permits the user to specify model structure; it does not impose one upon him. As a result, the applicability of the aid is exceedingly general. It may be used to structure virtually any dynamic, uncertain, decision problem with single or multiple objectives.
- Allows explicit representation of subjective uncertainty without requiring common oversimplifications concerning probabilistic independence or the shapes of probability distributions.

- Produces immediate and continual output of useful information. Consequently, it tends to motivate use and allows for random stopping.
- Provides assistance in the identification of important decision factors. As a result, it tends to guide the modeling process and reduces wasteful allocation of modeling effort.

4.2 Directions for Further Research

From this point, further research on the computer-aided structuring process can be profitably directed toward three ends. First, initial applications clearly indicate that the computer code should be streamlined and better integrated. The user must be given the the opportunity to move about the process, requesting previously displayed results as needed, with more freedom than is currently available. Second, to establish and better introduce the structuring process to the research community and decision analysis practitioners, demonstration projects should be presented in which the applications of the structuring process to a variety of practical problems are documented. Third, to better estimate the strengths, weaknesses, and potential of the structuring aid for use by those other than specialists in decision analysis, individuals other than its developers should objectively test the aid. The next subsection of this report contains some discussion of principles for testing the aid.

4.3 Principles for Testing

Most important for the testing of the computer-aided structuring process is a specification of a criterion for evaluating the extent to which the process improves decision-making. An obvious approach is to design standard decision problems to be used for testing. Solutions to these standard problems might be based on the combined judgment of a panel of experienced naval commanders. Experiments could then measure the extent to which subjects using the aid come closer to the prescribed solution than do subjects not using the aid.

Inherent in this approach, however, are a number of potential problems. First, the aid has been designed, by definition, for application to one-of-a-kind, unfamiliar decisions that have not been previously structured. Application to standardized decision problems may result in testing the aid on a class of problem for which it was not intended to be used.

An even more fundamental problem is the definition of a good decision. According to the discipline of decision analysis, a good decision is one that is consistent with the decision-maker's information and preferences. Thus, the structuring process is designed to help a user identify a decision strategy that is consistent with his <u>own</u> subjective preferences and information. Successful application of the aid can result in totally different decision strategies for individuals who have different information or preferences. Comparing the solution indicated by the structuring aid with the "right" solution generated by a panel of experts does not, therefore, directly measure the aid's ability to improve a decision-maker's performance. The user could conceivably believe that the strategy derived through the use of the aid was better, given his state of information and preferences, than that produced by the panel of experts. A formal decision analysis resulting in a quantitative model of the type produced by the structuring process may be a more effective way to generate a good decision strategy than the use of a panel of experts because of well-known group decision-making biases.

Once an adequate experimental design is selected, testing should attempt to answer several specific questions. Most importantly, if the aid fails to perform well, experimental design should indicate if the reason is the user's inability to provide appropriate input information, a more general problem with the decision-analysis modeling approach, a problem related to the specific algorithm utilized in the structuring process, or a problem with the computer aid design.

A variable that may affect the value of the aid to a user is the user's proficiency in decision analysis techniques. Consequently, testing should attempt to identify whether the effectiveness of the aid depends strongly on the user's familiarity with decision analysis. Because the structuring process design lends itself to a wide class of decision problems, testing should also attempt to determine whether specific kinds of decisions are more effectively aided than others. If this is the case, then the characteristics that tend to make the aid effective or ineffective should be identified.

Ease of use of the aid will be strongly influenced by input/output design, especially the use of graphics. Therefore, testing should attempt to identify what changes in computer aid design are needed to simplify its use. Finally, whatever criterion is adopted for measuring the ability of the aid to improve decision-making, some attempt should be made to assess the extent to which the users think that the aid is helping them. Specifically, does the aid help users to identify issues, does it help them to evaluate options, and, finally, do the users believe the aid helps them to formulate better decision strategies?

Appendix A

INSTRUCTIONS FOR USING THE SIMULATION BOARD

Appendix A

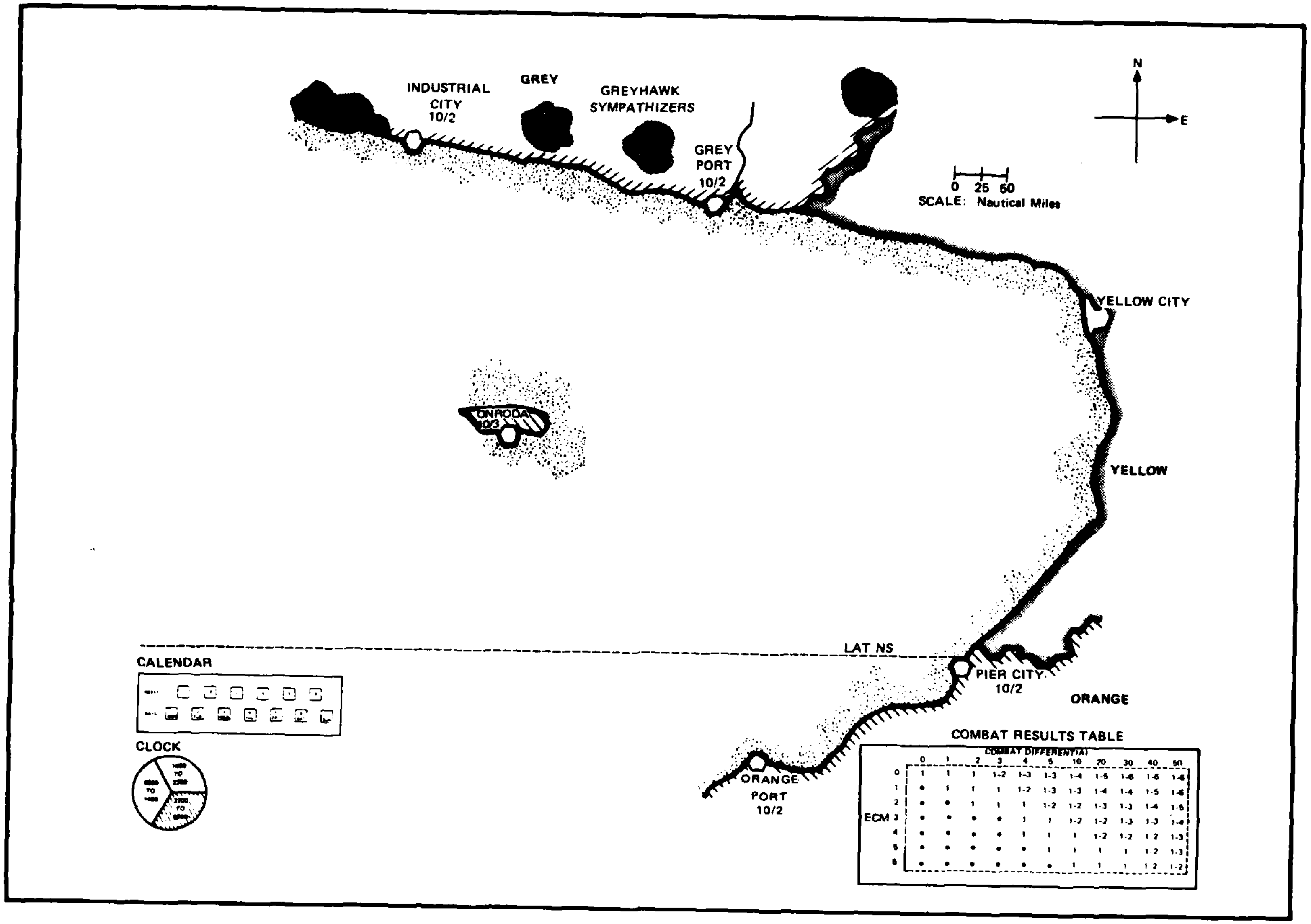
INSTRUCTIONS FOR USING THE SIMULATION BOARD

A.1 Introduction

The current configuration of the simulation board is based on the ONRODA scenario developed by the Naval Warfare Research Center at SRI International. There are two game players. One controls Blue and Grey, the other, Red and Orange. The rules of engagement are similar to "SEATAG," a simulation game developed at the Naval War College [18], and "Sixth Fleet," a simulation of operational naval warfare marketed by Simulations Publications, Inc. [19].

The cells on the simulation board (Figure A.1) are composed of seven small hexagons (hexes). The scale is such that each cell represents a distance of 50 nmi. Within a cell, units are distinguished according to their proximity to attacking units. Units in the closest two hexagons must be attacked first by an enemy unit. Likewise, the middle hexagons (excluding the center hexagon) are for units that are to be attacked second; the farthest position is for units that are to be attacked third. The center position is for units that are to be attacked last.

Three types of units are used: air, surface, and submarine. Each air unit represents a squadron of 12 airplanes; each surface and submarine unit represents one ship or submarine, unless otherwise indicated.



ECM \ Combat Differential	0	1	2	3	4	5	10	20	30	40	50
0	1	1	1	1-2	1-3	1-3	1-4	1-5	1-6	1-6	1-6
1	•	1	1	1	1-2	1-3	1-3	1-4	1-4	1-5	1-6
2	•	•	1	1	1	1-2	1-2	1-3	1-3	1-4	1-5
3	•	•	•	•	1	1	1-2	1-2	1-3	1-3	1-4
4	•	•	•	•	1	1	1	1-2	1-2	1-2	1-3
5	•	•	•	•	•	1	1	1	1	1-2	1-3
6	•	•	•	•	•	•	1	1	1	1-2	1-2

FIGURE A.1 THE SIMULATION BOARD

Displayed on each unit are numbers expressing its attack strengths, defense strength, electronic counter measures (ECM), and range of movement (see Figure A.2).

A.2 Movement

Movement of forces is allowed only during the movement phase. A unit can be moved to any position within its specified range of movement. Range is measured as the number of cells consecutively traveled by a moving unit. A unit cannot end its movement in a cell occupied by an enemy unit.

A.2.1 Zones of Control

A unit occupying a cell exerts a zone of control that extends through the six adjacent cells. Enemy zones of control may be entered, but entering units are forced to stop immediately on entering enemy zones of control unless and until the total attack strength of the detained units is greater than or equal to total attack strength of the controlling units. More than one unit may exert a zone of control over the same cell, but own zones of control never negate enemy zones of control. However, a unit may ignore the zone of control of an enemy unit that is incapable of attacking it.

A submarine unit may always leave an enemy zone of control. An air unit may leave an enemy zone of control if it does not immediately enter another enemy zone of control. A surface unit may leave an enemy zone of control only if: the enemy unit moves away; the enemy unit is destroyed or forced to retreat; the enemy unit consists only of air forces; or the

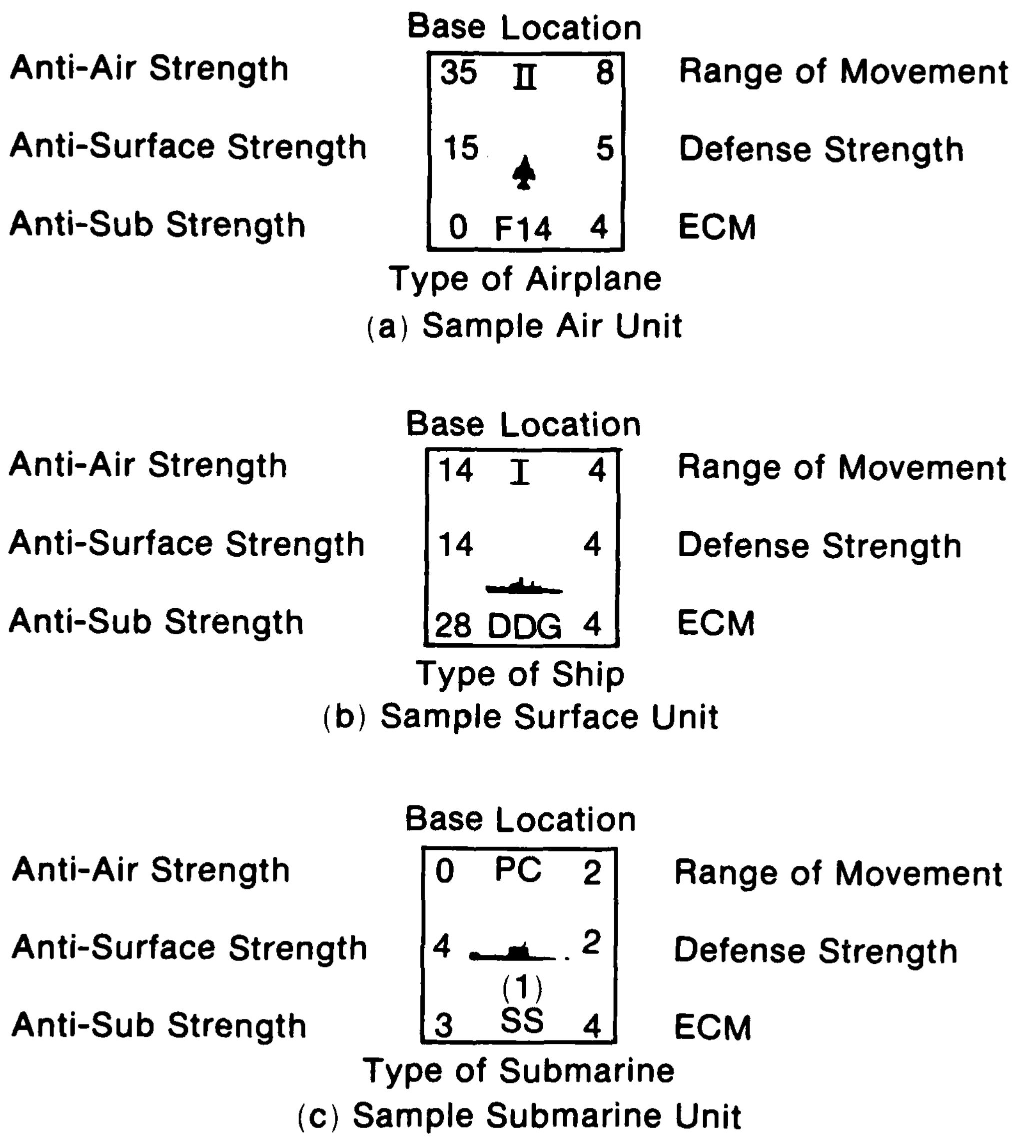


FIGURE A.2 TYPICAL SIMULATION PLAYING PIECES enemy unit has a range of movement less than the range of the surface unit.

A.2.2 Limits on Locations of Units

Surface or submarine units may not be stacked over a single hex. In addition, a maximum of six air units may occupy a hex at a given time. The only exceptions are at bases, where there is no limit (except ONRODA Island where the limit is 16 air units). Within a hex, the air units must be placed on top of surface and submarine units. Submarine units must be positioned below any surface units. Subject to these constraints, units may be rearranged during any own movement phase.

A.2.3 Red Units

War can be declared only by Red. Unless war has been declared, Red and Blue units do not engage in combat and may occupy adjacent hexes without exerting zones of control. Each may move through a cell occupied by the other, whenever unoccupied hexes in the cell are available. No combat between Red and Blue ensues until war is declared. Red air units may refuel at any Orange base.

A.2.4 Air Units

The range of an air unit is the radius it can travel from a base or carrier while retaining enough fuel to return. The maximum distance an air unit can travel on a "suicide" combat mission is twice its range. The maximum distance of an air unit that does not engage in combat is three times its range. Air units that begin a movement phase away from a base or carrier must immediately return to a base or carrier in the next movement phase. Any air unit that cannot return is destroyed, except for Blue air units landing at Grey bases that are eliminated but not destroyed. Once an air unit returns to a base or carrier, it can either remain aloft to provide an air defense, or it can be placed in bunkers (at bases) or in the hold (on carriers). Air units in bunkers or holds are eliminated only if the base or carrier is destroyed. A maximum of six air units may be launched at one time from each Orange base.

A.3 Combat

There are three different types of attack strength: antiaircraft, antisurface, and antisubmarine. In each combat phase, an attacking unit must use the attack strength of the appropriate type for the defending units. Each type of defending unit must be attacked separately. The attack strengths of a unit must not be split among attacks. Daylight air units have their attack strength halved at night (as indicated by the yellow band on the unit).

The procedure for combat is as follows. Ignore civilian air and surface units. The difference between the total of the appropriate attack strengths of the attacking units and the total of the defense strengths of the defending units is the combat differential for that engagement. This differential is rounded down to the nearest number in the columns of the combat results table. The row in the table is selected using the highest ECM value of any of the defending units. The intersection of the appropriate row and column in the table gives a bench mark for the roll of a die. If the roll of the die is less than or equal to the given amount, then the defending units must be immediately retreated to an adjacent, nonenemy-controlled cell. If such a retreat is not possible, then the defending units are eliminated. If the roll of the die is greater than the given amount, then the attack has no effect. A blank in the table indicates that the attack has no effect.

The attacking units may be used in any order and in any number to attack enemy units in an adjacent cell. Each attacking unit, however, may be used only once in a given combat phase. Attacking units ignore enemy units that they are incapable of attacking and engage the first unattacked unit they are capable of attacking. Air units must be attacked first, then surface units, and finally submarine units. Within a unit type, the defending units must be attacked in the order they are positioned and stacked in the cell, but may be attacked repeatedly by different attacking units. Units in separate cells must attack separately.

A.3.1 Mandatory Attacks

At least one own unit in each enemy-controlled cell must engage in combat at least one enemy unit in an adjacent cell. A unit may ignore an enemy unit that is incapable of attacking it. If the combat differential for a mandatory attack is greater than or equal to zero, then a unit has fulfilled its obligation to attack. If the combat differential for a mandatory attack is less than zero, then the unit must be immediately retreated to a nonenemy-controlled cell.

A.3.2 Retreat

A unit may never retreat into an enemy zone of control, even if that cell is controlled as well by an own unit. Air units can never retreat;

if a retreat is mandated, then they are eliminated. If forced to retreat because of insufficient attack strength, the unit may not engage in subsequent attacks during that combat phase.

Any cell completely vacated after the retreat of defending units may immediately be occupied by up to three attacking surface or submarine units, regardless of zones of control and without prejudice for future movements. Similarly, if all attacking units in a cell must retreat because they lack sufficient combat differential, then up to three defending surface or submarine units may occupy that cell. Movement into vacated cells is always optional.

A.3.3 Bases

Blue may not attack Orange bases or targets at Orange bases unless war is declared. Each base has a defense strength (DS) and an ECM measure, shown on the map as DS/ECM. Bases exert no zones of control. To destroy a base, the attacking units must first eliminate all units at that base. Bases have no attack strength. If they are defeated by an attacking unit, then an appropriate marker is placed on the base. Attacking units may move into a vacated base, as they choose.

A.4 Some Hints on Playing Strategy

(1) The rules allow great flexibility for retreat (giving up some ocean) rather than combat with potentially high losses.

(2) An often successful strategy is to force a retreat by attacking with units that have a high defense strength.

(3) Movement after combat allows the opportunity to escape following a particularly successful attack.

(4) Attacking units should have enough total strength to absorb any losses inflicted before the attack is launched.

(5) Air units are effective, yet vulnerable. They have good range and strength, but can be cut off from their base and forced to ditch.

(6) Care should be taken to keep from being surrounded. A surrounded unit that must retreat is eliminated.

A.5 Starting Locations

The initial location of the Blue task force is 400 nmi west of ONRODA. Carrier Group I and Carrier Group II are 50-100 nmi apart. Each carrier has an identical air wing composition.

Grey units are split between Industrial City and Grey Port. Four A4 units are out fighting the Greyhawk guerillas. Both DD units are at Grey Port. One F5 unit is at Grey Port, and two are at Industrial City.

Orange has 2 missile boat (MB) units, each with 3 boats, sitting 120°/60 nmi from the Blue task force. On ONRODA, Orange has 4 MIG21 units, 4 SU7 units, 2 MIG19 units, and 2 IL28 units. At Orange Port and Pier City, Orange has 8 MIG21 units, 4 MIG19 units, 2 SU7 units, 2 TU16A units, and 1 IL28 unit. The Orange DD units and SS units are at Pier City; 2 MB units and 2 torpedo boat (TB) units are at Orange Port.

Red forces are all at sea. A cruiser (CG) and a three-ship DD unit are 100 nmi west of ONRODA. One DD unit is 280 nmi west of ONRODA. One TU20 unit is flying 200 nmi southeast of the Blue task force. The rest of the Red fleet is 150 nmi southwest of ONRODA.

Appendix B

OPERATION OF THE COMPUTER AID FOR DECISION STRUCTURING

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OPERATION OF THE COMPUTER AID FOR DECISION STRUCTURING

This appendix describes details of the access, initialization, and operation of the aid as it was implemented on the ODA test bed. Should the aid be provided on another host computer system, the specifics of operation will likely differ somewhat from that described below.

B.1 Instructions for Logging onto the University of Pennsylvania Wharton Computer

1. Establish your connection to the computer (via ARPANET, dial up, etc.). You will receive the following message.

```
Wharton Schook KL 603A16 10:28:32 TTY144 system 1265
Please LOGIN or ATTACH
```

The monitor types a '.' to indicate that it is ready to accept a command. You will need a user code (XXXX,PPP), user name (NNNN), and passwords to complete logging onto this computer.

Type immediately after the period

LOGIN XXXX,PPP

followed by a carriage return. The computer will respond:

JOB XX Wharton School KL 603A16 TTYNNN

XX is the job number being assigned to your session, and TTYNNN identifies your communication line to the KL10.

You will be requested to enter your user name that has been specified for the KL10.

Name: ABC

Your password(s), which will not be echoed to your terminal, must next be entered.

Password(s):

When you are successfully logged on, you will be told the time, date, and day of the week and any system news briefs. You are ready to proceed when you receive a '.' at the left side of the terminal.

The following is an example of a successful log on to the Wharton Computer using the ARPANET.

```
SU TIP 424 #:  1
@o 83
Trying...
 Open

Wharton School KL 603A16 10:28:32 TTY144 system 1265
Please LOGIN or ATTACH

.login 2652,210
JOB 31 Wharton School KL 603A16 TTY144
Name: leaf
Password(s):
1029
19-Mar-81
Thur

User: LEAF last LOGIN on 18 March, 1981 at 16:31
as [2652,210] on TTY144

1 Piece of Regular Mail Waiting.
```

B.2 Entering the Decision Structuring Aid

Once you have successfully logged on and have received a '.' indicating that you may enter a command, you must enter the APL system to have access to the aid. Type

```
. r   new:apl
```

Your terminal type will be requested

```
terminal..
```

Typing H will cause the computer to print the list of terminal types that it supports. Most APL terminals are bit pairing (BIT) or type pairing (KEY). A non-APL terminal (e.g., the Ramtek color graphics terminal) is type TTY. Respond with the appropriate terminal code and a carriage return (if it is an APL terminal, be sure to change to the APL character set at this time).

The message

```
.r new:apl

termanal..key
APL-10 APLSF-10 WHARTON SCHOOL 2(435)
TTY146) 12:55:56 SATURDAY  7-MAR-81 LEAF  HURST  [2652,210]
CLEAR WS
```

will be printed when you have successfully entered APL. The cursor will indent six characters when APL is ready to accept a command. You must first request the size work space needed to run the aid. The MAXCORE command will allocate the required memory,

```
)MAXCORE   40
```

The computer will respond with the previous amount of core that was allocated to you. You next retrieve the workspace SKELET that contains the aid:

```
)LOAD   SKELET
```

A message indicating the date SKELET was last modified and its memory size is printed when the workspace is loaded. The aiu can now be entered by typing GO. The following sequence of questions and statements will be initiated.

```
GO

GRIN?  N__
RAM?  Y__
OFFICE OF NAVAL RESEARCH / SRI INTERNATIONAL DECISION
STRUCTURING AID.

1981/ 3/ 7  SRI/ONR DECISION STRUCTURING TOOL    13:53: 7
IF YOU DO NOT UNDERSTAND ANY PROMPT, TYPE 'HELP' OR AN
EMPTY CARRIAGE RETURN FOR MORE EXPLANATION.

FOR AN EXPLANATION OF SOME OF THE PROMPTING FEATURES TYPE 'EXPLAIN'.

DECISION PROBLEM NAME:  SAMP
IS SAMP A  NEW PROBLEM?  YES
```

The questions GRIN? and RAM? require a yes or no response. Specify yes to GRIN? if you have the Grinnel available and yes to RAM? if you have a Ramtek available.

The aid maintains a library of problems that can be at different stages of development. This library is searched for the problem you have requested. If it does not find that problem in its library, it will have you verify that it is a new problem. If you respond no, you will receive a list of the problems already in the library, and you will be asked for your decision problem name again.

If you are starting a new problem, you will be automatically started at the objectives and outcome identification function of the preliminary structuring phase.

If you are working on a previously started problem, you will be asked:

WHAT WOULD YOU LIKE TO DO?

Many responses are allowable. A response P will allow you to proceed from where you left off the last time you saved the problem. You may also specify that you would like to return to an earlier point in the process, or you may request to have the model influence diagram or the tree displayed if you have progressed to those points in the process. You cannot, however, skip steps in the process. If you try to skip steps, you will be notified, and the list of what you can do next is printed.

You can exit from the structuring aid at any of the following points:

- Preliminary structuring phase
  - Before alternative generation
  - Before alternative evaluation
  - End of the phase.

- Modeling phase
  - After specifying the influence diagram
  - After constructing the decision tree
  - At any point during outcome estimation (by responding stop)
  - End of the phase.
- Expansion Phase
  - After identifying critical events
  - After adding new variables to the influence diagram
  - After defining the expanded decision tree
  - End of the phase.

At each of these possible termination points you will be asked:

DO YOU WANT TO CONTINUE WITH THE STRUCTURING PROCESS?

You must respond Yes or No. If you answer yes, the process continues. If you answer no, you will be asked:

SAVE BEFORE STOPPING?

Again, a yes or no answer is required. If you answer no, the work you have will not be saved.

When you continue working on a previously initiated problem, you will receive the following prompt:

WHAT WOULD YOU LIKE TO DO?

Possible responses and their meanings are:

P	Proceed from point of previous termination
S	Begin preliminary structuring phase
AG	Begin alternative generation function
AE	Begin alternative evaluation function
SV	Begin modeling phase (select variables for influence diagram)
SI	Specify influences in influence diagram
TS	Begin decision tree construction function (tree specification)
OE	Estimate outcomes in decision tree
TEV	Evaluate decision tree (tree evaluation)
TEX	Begin expansion phase (tree expansion)
AV	Add variables to the influence diagram
DISID	Display the influence diagram
DISTREE	Display the decision tree
RO	Review and change outcome variable values
HELP	Prints this list of possible responses

Not all of these responses are acceptable, however, because as noted earlier, the aid will not permit the user to enter at a point in the process that is beyond the point that was previously reached when the work was last saved.

B.3 Hints on Responding to Questions

The type of answers required by the aid are generally straightforward and apparent from the sample problem in this report. However, some further explanation may be helpful.

Many questions in the aid require narrative responses, such as, "What is the incentive or reason for the assigned task?" There are also questions in the aid which can have lists of narrative answers such as, "What is the objective of the mission?"

A narrative response can be terminated by having the last character on the line be a period (or by making a carriage return the sole response). The aid has no restrictions on the length of a narrative answer. A long answer could be entered with many lines (using carriage returns) or entered on one continuous "line" (when the cursor reaches the right-hand side of the screen, the terminal moves the cursor to the beginning of the next row on the screen).

Each response in a list is individually ended in the same manner as a narrative (with a period or a blank carriage return). If an error is made in any response, it may be corrected in the current line by backspacing the cursor to the beginning of the error, then typing a linefeed character, and correcting the information. This is the normal APL method of correcting input errors. Currently, there is no allowance in the aid to modify an answer (or line of an answer) after a carriage return has been sent.

The acronyms that are requested in the modeling and expansive phase are restricted in length to nine characters. Anything beyond the ninth character will be ignored. These acronyms are used for displays on the graphics terminals that do not have the APL character set. You will be more satisfied with the graphics display if you refrain from using any of the special APL characters in your acronyms. Spaces will be preserved exactly as you have typed them.

At several points in the preliminary structuring phase, the user is directed to use the simulation board. The aid will not proceed until you signal that you are ready. The signal is simply to type a carriage return.

When the decision tree is being constructed, the probabilities of outcomes are requested. The probability for each branch should not exceed 1.0.

When values are being specified for the outcome variables, the best, low, and high estimates are elicited. These correspond to the 50%, 10%, and 90% points on a cumulative probability distribution fitted to the variable.

The absolute minimum and maximum (0% and 100% points of the cumulative distribution) have been previously determined for the allowed outcome variables. The values you enter and the previously defined lower and upper limits must be in monotonically ascending or descending order. If the points are not properly ordered, you will be so notified, and the values will be requested again.

B.4 Remote Site Operations

If you are running the aid from a remote site, you must log onto the computer separately with your graphics terminal. After you have specified your problem name, you should enter the following commands from the graphics terminal (which must also be in the APL system)

```
)LOAD   RAM
 GRAB
```

This will cause the alphanumeric and the graphics terminal to be coordinated.

B.5 Additional Instructions for Experienced APL Users

This decision aid was developed for use by personnel with minimal computer experience. An experienced user can do several things that will override the strict program control built into the aid. For example, the user can stop the aid at any point by typing a BREAK character (two control Cs in succession if using the ARPANET) and saving the results using the APL system command ")WSID" to create a new workspace. The aid can be restarted at a later time by loading the new workspace and entering the sequence "→⎕LC." This will start the aid at the line that was being executed when it was interrupted. If the aid was waiting for a response when it was interrupted, the cursor will wait at the left-hand side of the screen for the response.

The aid can also be halted when it is waiting for a response by overstriking the characters OUT. The procedure is to type the character O, backspace, type U, backspace, type T and a carriage return.

B.6 Changing the Value Model

The aid is currently set to use a predefined value model with primary outcome variables SORTIES, PROB WAR, SHIP LOSS, and AIR LOSS. The outcome variable SHIP LOSS is determined by secondary outcome variables CG and CV losses. Similarly, the variable AIR LOSS is determined by secondary outcome variables F14, A7, and A6 losses.

The values of the outcome variables that do not comprise secondary outcome variables are assessed directly. Outcome variables that do comprise secondary outcome variables are calculated from the values that are directly assessed for the secondary outcome variables.

To store the value models, the aid uses information in segments 138, 139, 140, 141, and 142 of the disk file QUEST.EXM (as implemented on the Wharton Computer). The contents of these segments are:

Segment Number	Contents and Description
138	The names of the outcome variables (a character array with nine columns and a row for each outcome measure).
139	This is a numeric array with one row for each primary outcome variable and one column for each secondary outcome variable that is assessed directly. For an outcome variable that is assessed directly, the values in that row of the matrix should have 1.0 in the column corresponding to that variable and remaining values of 0.0. For an outcome measure that is not assessed directly, the values to be used to weight the variables for calculating value should be in the appropriate columns. The rows correspond to the rows in segment 138 and columns to the rows in segment 140.
140	The names of those outcome variables that are assessed directly (a character array with nine columns and one name in each row).
141	This is a numeric vector containing the relative weights of the outcome variables. A variable that is a loss should have a negative weight. This ensures that losses will be minimized and gains will be maximized.
142	This is a numeric array having two columns. These are the 0% and 100% points on the cumulative probability distributions of the outcome measures. The rows correspond to the order in segment 140.

Currently the data in these segments are:

```
138   SORTIES
      PROB WAR
      SHIP LOSS
      AIR LOSS

139   1   0   0   0   0   0   0
      0   1   0   0   0   0   0
      0   0  10   1   0   0   0
      0   0   0   0   6   3   1

140   SORTIES
      PROB WAR
      CG
      CV
      F14
      A7
      A6

141   -0.003 -9.12 -17.65 -1

142   0  3450
      0     1
      0     2
      0     2
      0    48
      0    48
      0    24
```

To illustrate the definition and meaning of these structures, notice, for example, that the fourth outcome measure is AIR LOSS. The fourth row of segment 139 has the values 6, 3, and 1 in the 5th, 6th and 7th columns. The 5th, 6th, and 7th outcome variables are F14, A7, and A6. Thus,

$$\text{AIR LOSS} = 6 \times \text{F14} + 3 \times \text{A7} + 1 \times \text{A6} \quad .$$

Similarly, for the outcome measure SHIP LOSS, using the 3rd row of segment 139 and segment 140,

$$\text{SHIP LOSS} = 10 \times \text{CG} + 1 \times \text{CV} \quad .$$

Using the values in segment 141, the outcome for a scenario is

$$- 0.003(\text{SORTIES}) - 9.12(\text{PROB WAR}) - 17.65(\text{SHIP LOSS}) - \text{AIR LOSS}$$

The data in Segment 142 specify that the maximum number of sorties that could occur in the relevant time span is 3450. The probability of war cannot exceed 1.0 nor be less than 0.0.

When changing the outcome variables, and/or the value model, these five segments must be changed to preserve the types and the relationships among the dimensions of these data elements in the appropriate segments of the data file QUEST.EXM.

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ODA DISTRIBUTION LIST

Director, Engineering Psychology
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Office of Naval Research
800 North Quincy Street
Arlington, VA 22217 (5 cys)

Defense Technical Information
Center
Cameron Station, Bldg. 5
Alexandria, VA 22314 (12 cys)

CDR Paul Chatelier
Office of the Deputy Under
Secretary of Defense
OUSDRE (E&LS)
Pentagon, Room 3D129
Washington, DC 20301

Dr. Craig Fields
Director, Cybernetics Technology
Office
Defense Advanced Research
Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

Office of the Chief of Naval
Operations, OP987H
Personnel Logistics Plans
Washington, DC 20350

Dr. A. L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, DC 20380

Commanding Officer
ONR Eastern/Central Regional
Office
Attn: Dr. J. Lester
Bldg. 114, Section D
666 Summer Street
Boston, MA 02210

Commanding Officer
ONR Branch Office
ATTN: Dr. Charles Davis
536 South Clark Street
Chicago, IL 60605

Commanding Officer
ONR Western Regional Office
ATTN: Dr. E. Gloye
1030 East Green Street
Pasadena, CA 91106

Commanding Officer
ONR Western Regional Office
ATTN: Mr. R. Lawson
1030 East Green Street
Pasadena, CA 91106

Tactical Development & Evaluation
Support
Code 230
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Operations Research Program
Code 434
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Statistics and Probability Program
Code 436
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Information Systems Program
Code 437
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Dr. James McGrath
Code 311
Navy Personnel Research and
Development Center
San Diego, CA 92152

Management Support Department
Code 210
Navy Personnel Research and
Development Center
San Diego, CA 92152

Naval Electronics Systems Command
Human Factors Engineering Branch
Code 4701
Washington, DC 20360

Director
Naval Research Laboratory
Technical Information Division
Code 2627
Washington, DC 20375

Mr. Arnold Rubinstein
Naval Material Command
NAVMAT 08D22
Washington, DC 20360

Commander, Naval Electronics
Systems Command
Command and Control Division
Code 530
Washington, DC 20360

Dr. John Silva
Head, Human Factors Division
Naval Ocean Systems Center
San Diego, nA 92152

Commander
Naval Electronics Systems Command
C3 Project Office
PME 108-1
Washington, DC 20360

Dr. Julie Hopson
Human Factors Engineering
Division
Code 604
Naval Air Development Center
Warminster, PA 18974

CDR P. M. Curran
Code 270
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Dr. Jesse Orlansky
Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

Human Factors Department
Code N215
Naval Training Equipment Center
Orlando, FL 32813

Dr. Gary Poock
Operations Research Department
Naval Postgraduate School
Monterey, CA 92940

Dr. Joseph Zeidner
Technical Director
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Chief, Systems Effectiveness Branch
Human Engineering Division
Wright Patterson AFB, OH 45433

Dr. H. W. Sinaiko
Smithsonian Institution
801 N. Pitt Street
Alexandria, VA 22314

Office of the Chief of Naval
Operations OP942
Pentagon
Washington, DC 20350

Office of the Chief of Naval
Operations OP987C
R&D Plans Division
Washington, CA 20350

Dr. Chantee Lewis
Management Department
Naval War College
Newport, RI 02840

M. L. Metersky
Naval Air Development Center
Code 5424
Warminster, PA 18974

Dr. Edgar M. Johnson, Director
Organizations & Systems Research Laboratory
U.S. Army Research Laboratory
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. David Dianich
Chairman, Dept. of Business and Economics
Salisbury State College
Salisbury, MD 21801

Mr. Victor Monteleon
Naval Ocean Systems Center
San Diego, CA 92152

Commander, Naval Electronics Systems Command
ELEX-03
Washington, DC 20360

CDR Richard Schlaff
NIPSSA
Hoffman Bldg. #1
2461 Eisenhower Avenue
Alexandria, VA 22331

Mr. George Pugh
Decision Science Applications, Inc.
1500 Wilson Boulevard
Arlington, VA 22209

Dr. Arthur Siegel
Applied Psychological Services
Science Center
404 E. Lancaster Street
Wayne, PA 19087

Mr. David Walsh
Integrated Sciences Corporation
1640 Fifth Street
Santa Monica, CA 90401

Dr. John Shore
Naval Research Laboratory
Code 5403
Communications Sciences Division
Washington, DC 20375

Dr. Meredith Crawford
American Psychological Association
Office of Educational Affairs
1200 17th Street, NW
Washington, DC 20036

Dr. William Dejka
ACCAT
Naval Ocean Systems Center
San Diego, CA 92152

Mr. Merlin Malehorn
Office of the Chief of Naval Operations (OP102)
Washington, DC 20350

Dr. S. D. Epstein
Analytics
2500 Maryland Road
Willow Grove, PA 19090

Dr. Amos Freedy
Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

Dr. G. Hurst
University of Pennsylvania
Wharton School
Philadelphia, PA 19174

Mr. Tim Gilbert
MITRE Corporation
1820 Dolly Madison Blvd.
McLean, VA 22102

Mr. Leslie Innes
Defence & Civil Institute of Environmental Medicine
P.O. Box 2000
Downsview, Ontario M3M 3B9
Canada

LCDR J. A. Sears
Department of MIS
College of Business Administration
University of Arizona
Tucson, AZ 85721

Dr. Kenneth Gardner
Applied Psychology Unit
Admiralty Marine Technology
Establishment
Teddington, Middlesex TW11 OLN
ENGLAND

Dr. Rex Brown
Decision Science Consortium
Suite 421
7700 Leesburg Pike
Falls Church, VA 22043

Dr. A. C. Miller III
Applied Decision Analysis
3000 Sand Hill Road
Menlo Park, CA 94025

Mr. Joseph Wohl
MITRE Corporation
Box 208
Bedford, MA 01730

DATE
ILME